NASA/JPL Workshop on Extreme Environment Electronics
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HARSH ENVIRONMENT CHALLENGES FOR AUTOMOTIVE ELECTRONICS

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OUTLINE

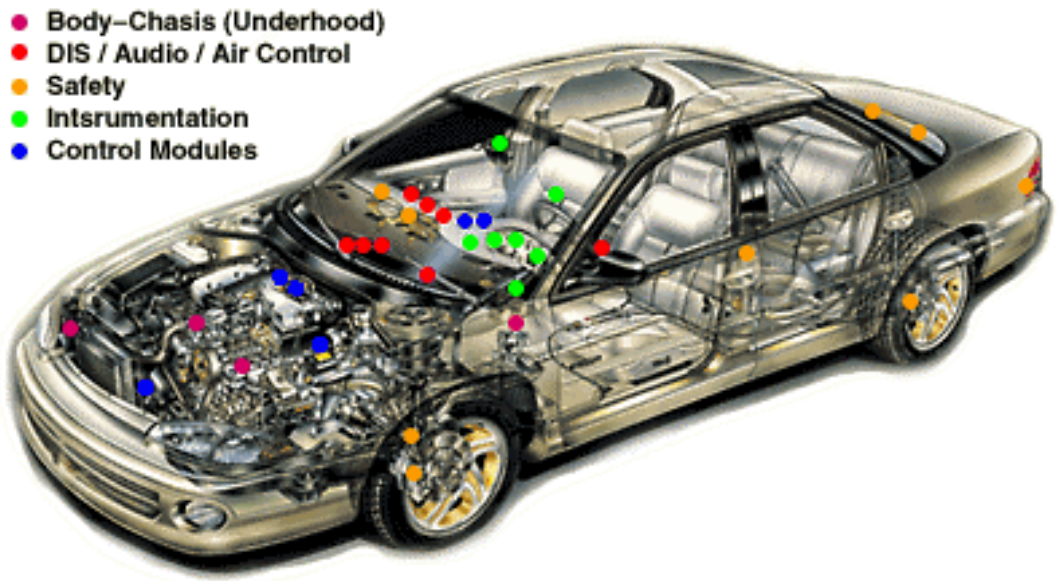
- Introduction to Automotive Electronics
- Future Trends
- Harsh Environment Challenges
- Temperature Ranges Seen by Underhood Electronics
- Strategies for Future Underhood Engine Controllers

- CAVE - Center for Advanced Vehicle Electronics
- Example Research Projects

INTRODUCTION

Automotive Electronics

- Automotive Electronics have Evolved into Complex Computer Systems Performing Functions Like Fuel Injection and Emission Control, Anti-Skid Braking, Active Suspension, and Electronic Transmission Control



INTRODUCTION

Automotive Electronics

- Average Cost of the Electronics in a Vehicle is Expected to Increase 1.5X in the Next 10 Years
- Major Projected Growth Areas
  - Hybrid Vehicle Electronics
  - Collision Avoidance and Protection Systems
  - Electronic Steering and Vehicle Stability
  - Powertrain Management
- Future Electronic Systems Must Meet Automotive Accelerated Life Testing and Vibration Requirements, While Exceeding 10 Years and 100,000 Miles of Operation

INTRODUCTION

Automotive Electronics

- Driving Forces for Automotive Electronics
  - Increasing Customer Demands
  - Safety
  - Comfort
  - Convenience
  - Legal and Political Requirements
  - Efficiency
  - Environment
- Trends in Automotive Electronics
  - Rapidly Increasing Functionality
  - Modular Architectures
  - Increased Networking
  - Higher Degree of Integration
  - Mechatronics: *Electronics Migrate to the Extreme Temperature Locations*

INNOVATIONS

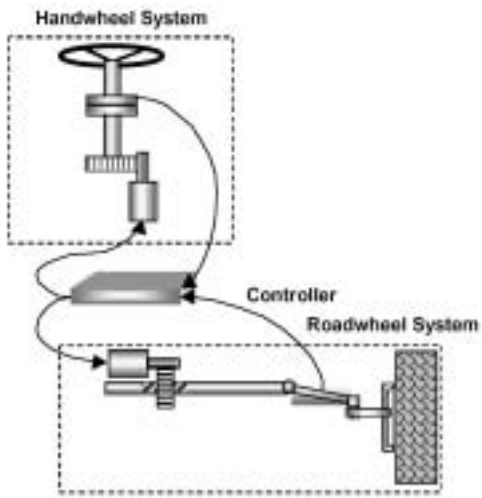
Automotive Electronics

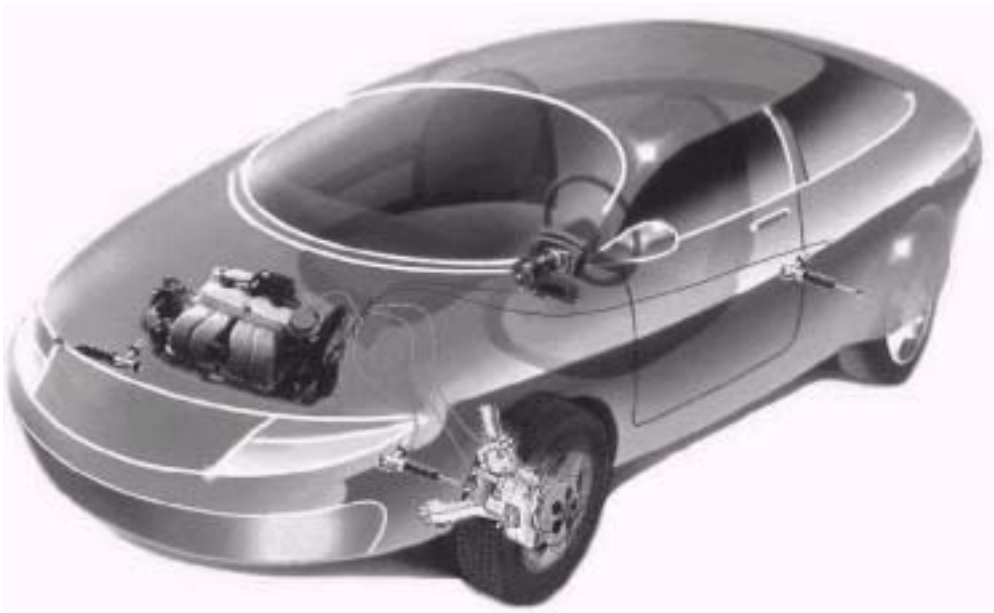
- Drive-by-Wire Control Systems
- Collision Avoidance
- Advanced Safety Interiors
- Advanced Energy Systems
- Advanced Thermal Comfort Systems
- Modular Chassis Systems
- Mobile Multi-Media, Telematics
- Smart Sensors and Actuators
- Integrated Vehicle E/E System

INNOVATIONS

Automotive Electronics

- Drive-by-Wire Control Systems
  - Throttle
  - Steering
  - Braking
  - Shifting
  - Suspension Adjustment

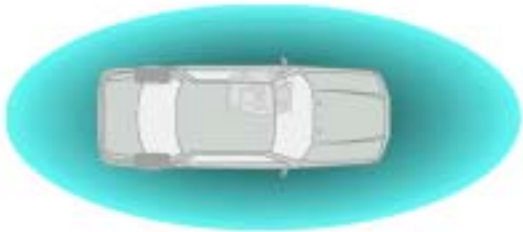


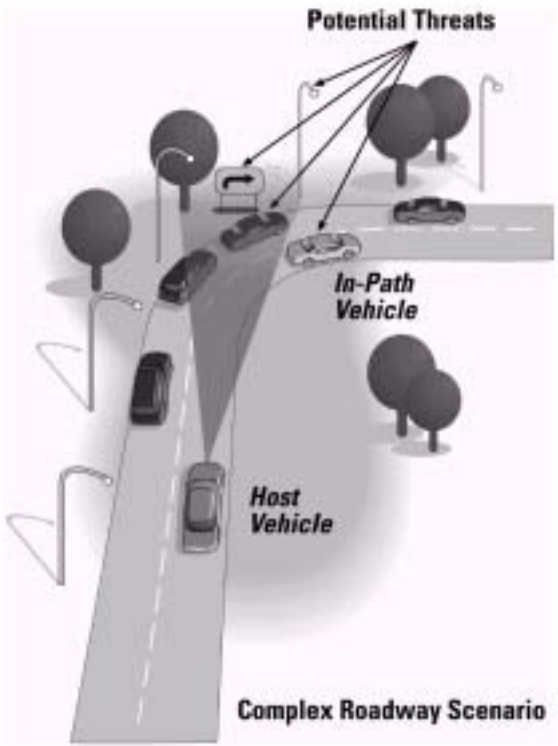


INNOVATIONS

Automotive Electronics

- Collision Avoidance Systems
  - Radar and Vision Sensors
  - Warning Displays
  - Brake, Throttle, and Steering Control Systems (X-by-wire)
  - Approaches
    - » Inform the Driver of Impending Danger of Either a Collision or an Out of Control Situation That Could Lead to a Dangerous Consequence (e.g., Rollover)
    - » Take Control of the Automobile and Make Corrective Action to Advert Danger in Parallel With a Warning to the Driver.

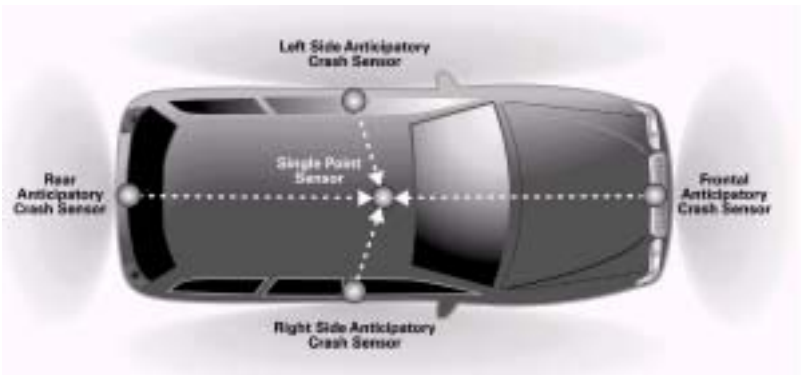


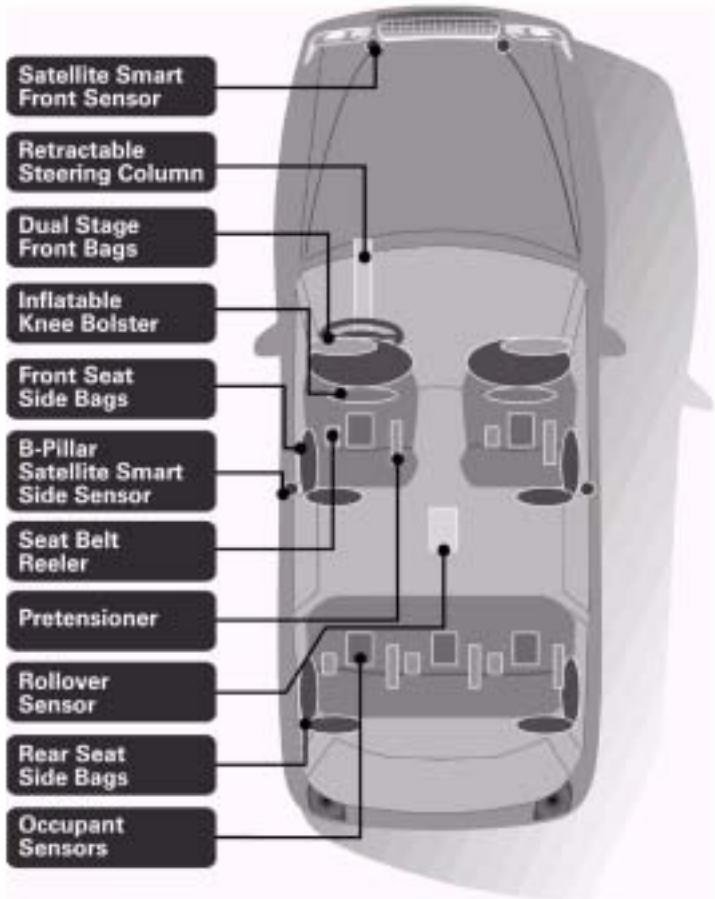


INNOVATIONS

Automotive Electronics

- Other Safety Improvements
  - Braking Systems with Electronic Stability Control
  - Adaptive Cruise Control
  - Full Environment Airbag Deployment
  - Tire Pressure Monitoring





INNOVATIONS

Automotive Electronics

- Advanced Energy Systems
  - 42 Volt Battery System to Support Increased Loads in Future Vehicle Systems and Integrated Starter Alternator (ISA)
  - Hybrid or Electric Vehicles
    - » Fuel Cells
    - » Super-Capacitors and Flywheels
    - » Advanced Batteries
    - » Electric Motor Drives


Ford P2000 Prodigy


DaimlerChrysler ESX3

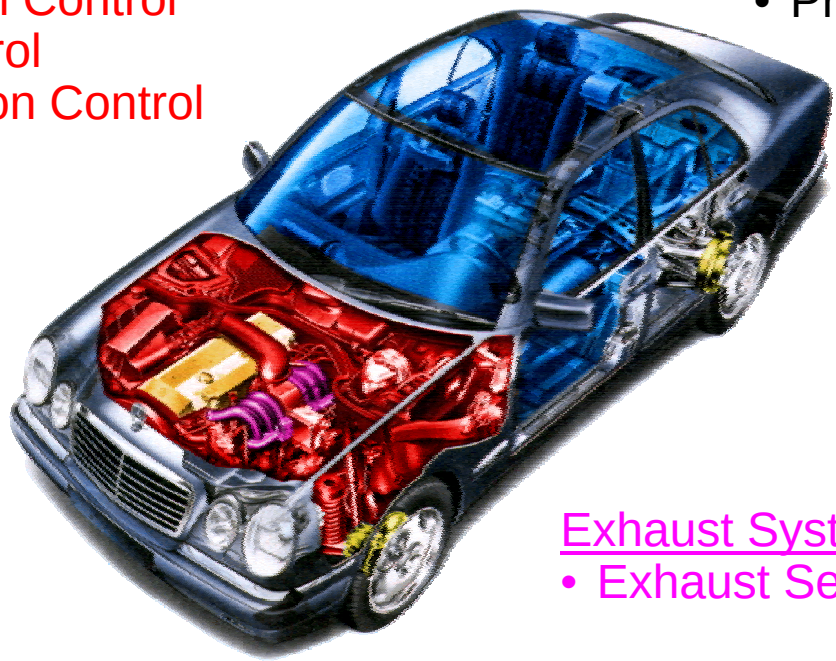

General Motors Precept

HARSH ENVIRONMENTS

Automotive Electronics

Engine Compartment: < 150°C
- Power Train Control
- Motor Control
- Transmission Control

Combustion Chamber: < 500°C
- Pressure Sensors



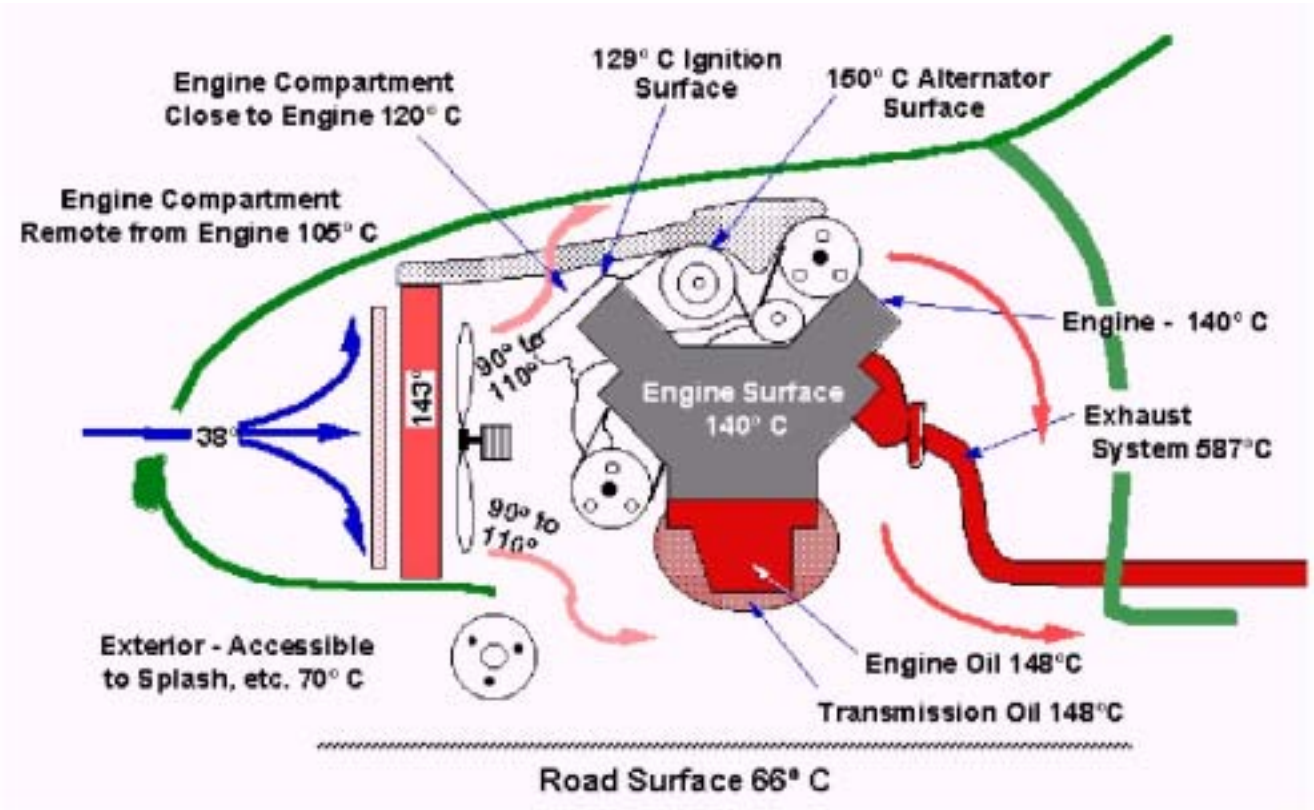
Exhaust System: < 800°C
- Exhaust Sensors

Engine, Transmission: < 200°C
- Engine-Mounted ECUs
- Integrated TCUs
- Shift-by-Wire

Wheel Mounted Components: < 300°C
- Brake-by-Wire
- Steer-by-Wire

HARSH ENVIRONMENTS

Automotive Electronics



Engine Compartment Thermal Profile

LIFE TESTING

Automotive Electronics

Consumer	0 to 100 °C
Military	-55 to 125 °C
Automotive	-40 to 125 °C
Automotive (Passenger Compartment)	-40 to 85 °C
Automotive (Underhood Remote)	-40 to 105 °C
Automotive (Underhood)	-40 to 125 °C
Automotive (On-Engine)	-40 to 150 °C
Automotive (On-Transmission)	-40 to 175 °C
Automotive (Wheel Based)	-40 to 250 °C
Automotive (Exhaust)	-40 to 800 °C

Typical Reliability Specifications for Automotive Control Modules Include the Ability to Survive 1500-2500 Cycles During Accelerated Life Testing

HARSH ENVIRONMENTS

Automotive Electronics

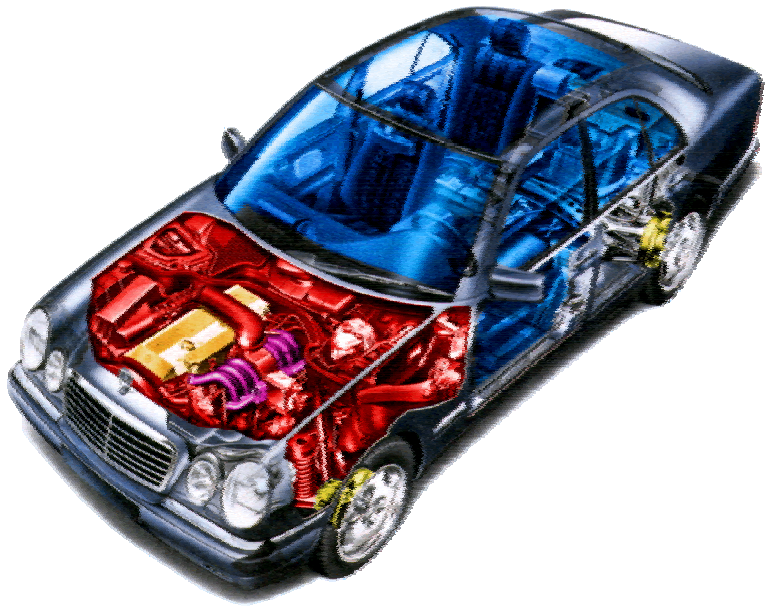
Typical Reliability Requirements – Add Vibration

Device Type	Automotive Environment		
	Electronic Control Unit (ECU)		Sensor
Location	"Under-hood"	On-engine On-transmission	On-Engine
Temperature Range (~2500 cycle lifetime)	-40 °C ⇔ +125 °C	-40 °C ⇔ +150 °C	-40 °C ⇔ +175 °C
Vibration, Typical	≤ 3 g	≤ 10 g	≤ 40 g
Shock, Typical	≤ 20 g	≤ 30 g	≤ 50 g

TECHNOLOGY

Automotive Underhood Engine Control Modules

Yesterday



Today

TECHNOLOGY

Automotive Underhood Engine Control Modules

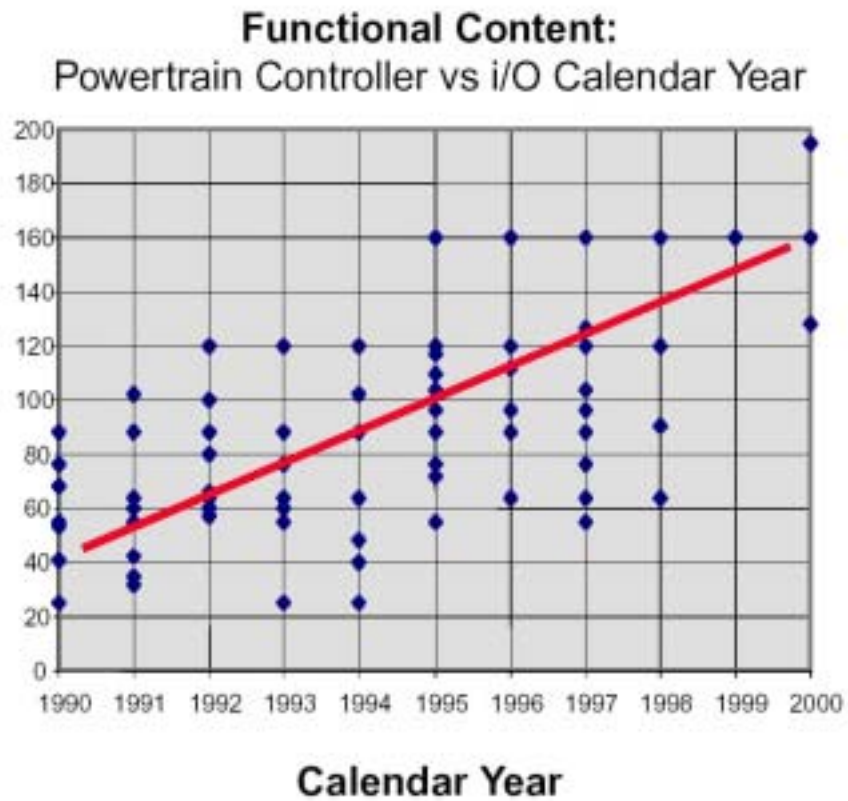
- Automotive Underhood Control Modules Feature "*Mass Production Harsh Environment Consumer Electronics,*"
- COTS…
- Controller Complexity Drivers:
  - Legislation
  - Market
- To Support the Increase in Feature Content, Additional "Smart" Subsystems have been Added to Provide Detailed and Fast Electromechanical Interface

Engine Management Trends

Feature	1995	2000	2005
Electronic Fuel Injection	•	•	•
Knock Detection	•	•	•
Engine Performance	•	•	•
Coil On Plug		•	•
Integrated Solenoid Pack		•	•
Advanced Engine Control		•	•
New Emissions Standards		•	•
EMI Reduction	•	•	•
Advanced Packaging		•	•
Drive By Wire			•
Continuously Variable Transmission			•
Electronic Throttle Control			•
Gas Direct Injection			•
Common Rail Diesel			•
Torque Management			•
Electronic Transfer Case			•
On Board Diagnostics II	•	•	•
On-Powertrain Controller			•
J1850		•	•
CAN		•	•
VVT – Variable Value Timing			•

TECHNOLOGY

Automotive Underhood Engine Control Modules



LOCATION HISTORY

Engine/Powertrain Control Modules

Locations

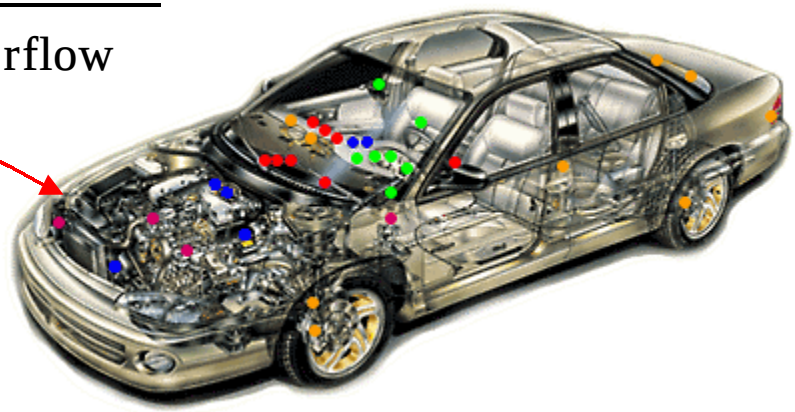
- Passenger Compartment
- Firewall
- On-Engine / On-Transmission

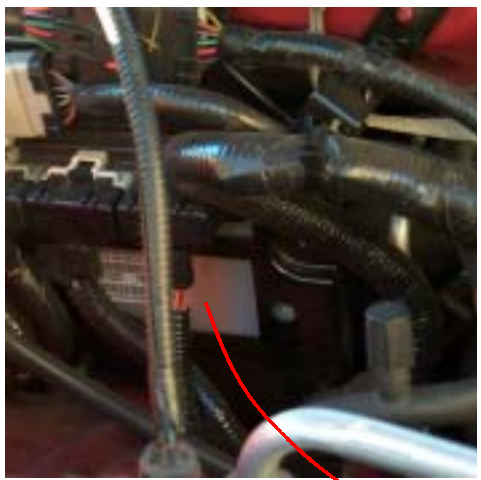
- Reasons for Shifts
  - Increased Complexity
  - Wiring/Connector Reliability Problems
  - EMI/RFI Problems
  - Vehicle Level Assembly and Test Issues
  - Cost, Size, and Weight Reduction

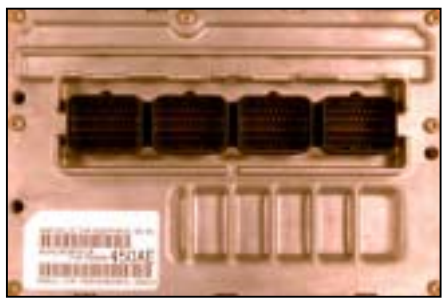
LOCATION

Automotive Underhood Engine Control Modules

- Firewall Mounted Module
  - Limited but Nonzero Airflow
  - -40 to 125 °C



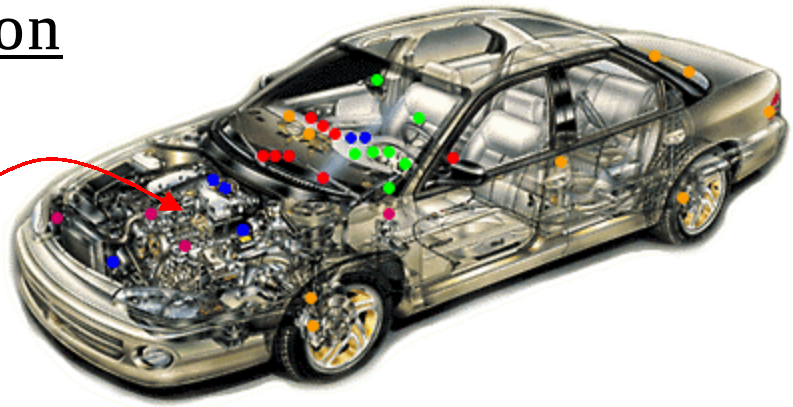


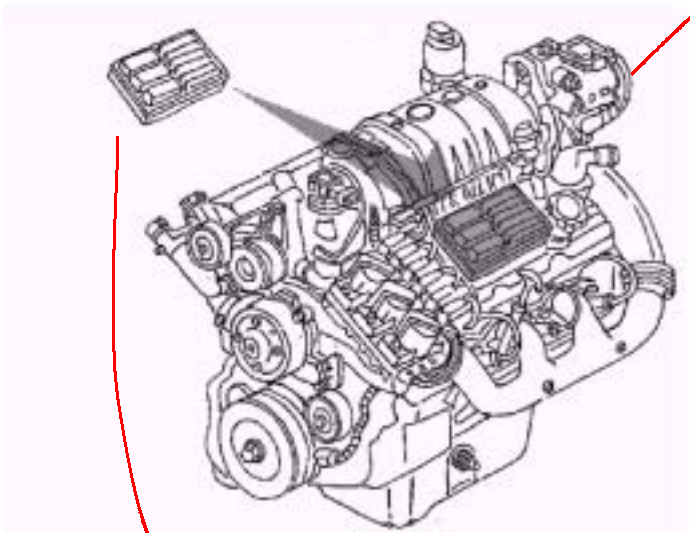


LOCATION

Automotive Underhood Engine Control Modules

- On-Engine/Transmission
  - -40 to 150 °C
  - -40 to 175 °C

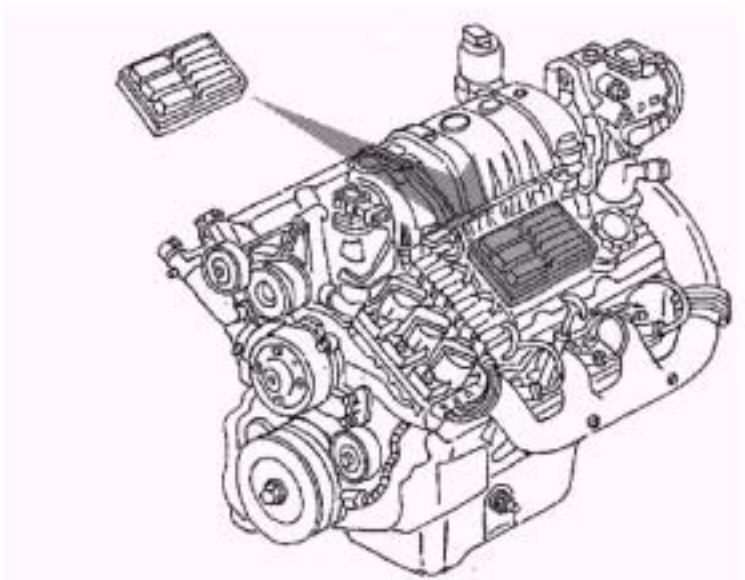




CONTROL MODULES

Strategies for On-Engine and On-Transmission

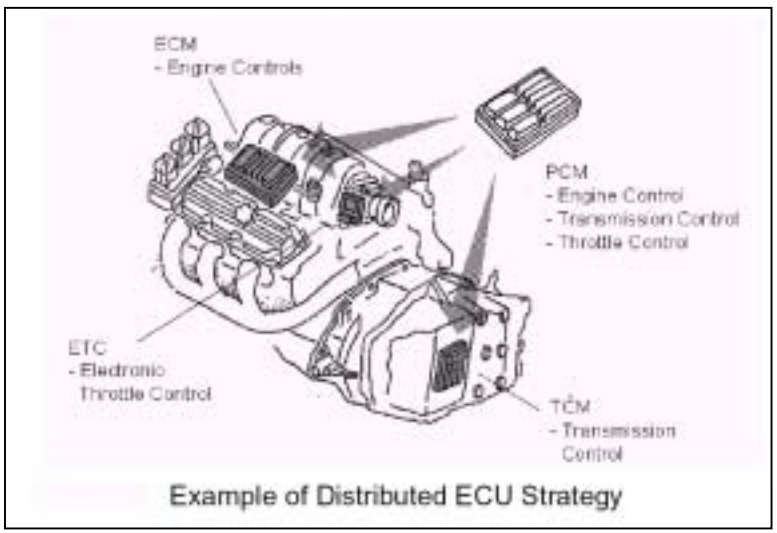
- Single Complex Module
  - Capable of Monitoring and Adjusting a Large Number of Inputs and Outputs in Real Time
  - Becoming Increasingly Difficult As Systems Require More Feature Content Which Increases Module Packaging Size and Vehicle Wiring



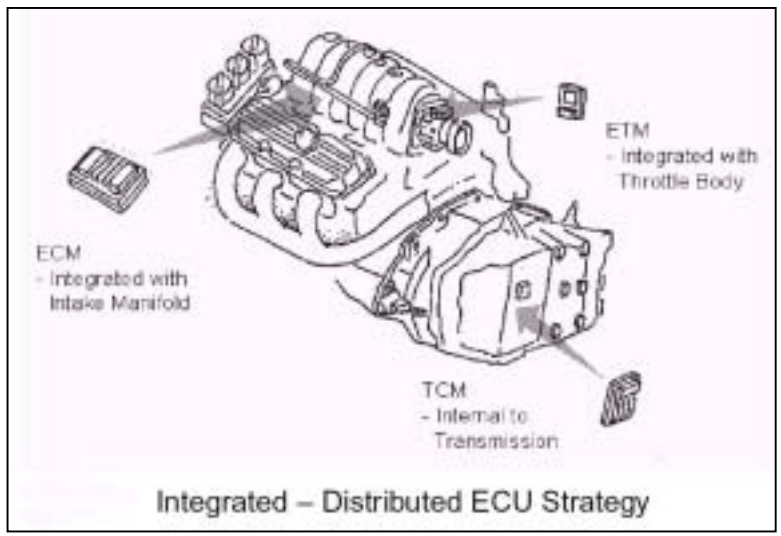
CONTROL MODULES

Strategies for On-Engine and On-Transmission

- Distributed Control System
  - Involves a Number of Smart Powertrain Modules Each Performing a Series of Specific Operations
  - System Is Integrated Through a Communications Bus
  - Systems Such As Continuously Variable Transmissions, Brake-by-wire, and Adaptive Steering Systems Must Allow for Electronic Controls to Be Married Into the Mechanical Environment



Example of Distributed ECU Strategy

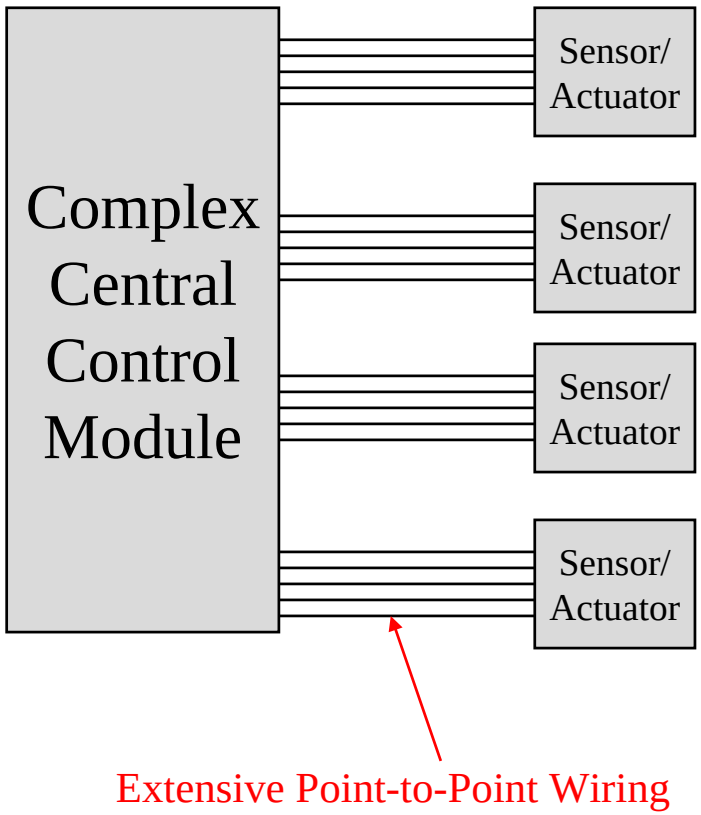


Integrated – Distributed ECU Strategy

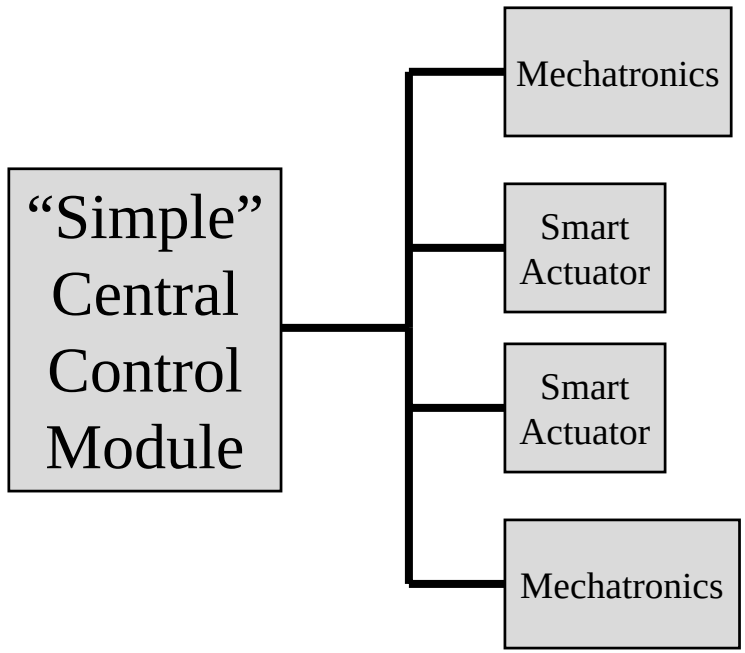
CONTROL MODULES

Strategies for On-Engine and On-Transmission

Typical Single Complex Controller Architecture



Integrated-Distributed Mechatronic Controller Architecture



CONTROL MODULES

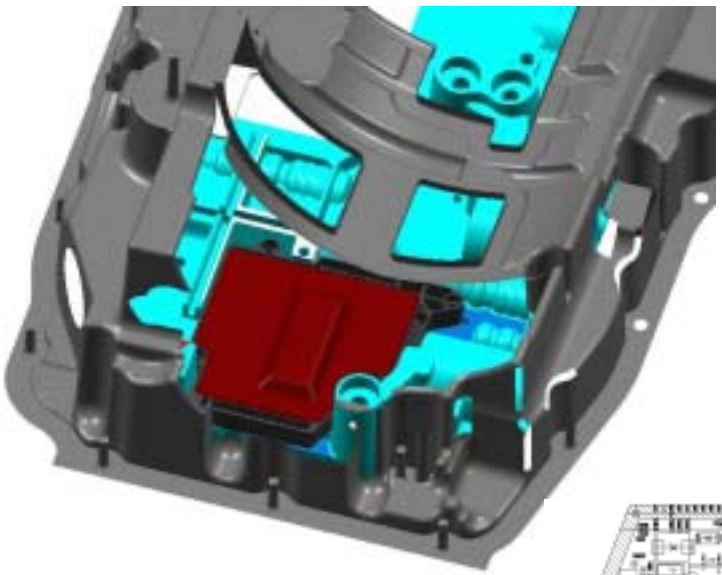
Advantages of Mechatronic Approach

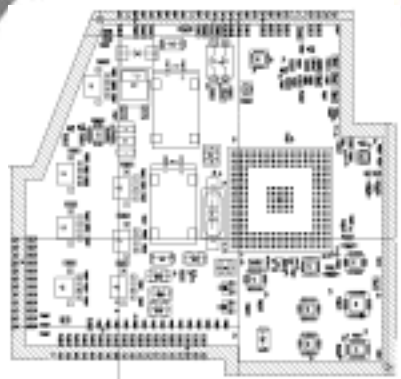
- Allows Modular Assembly and Test Strategies (Known Good Engine)
- Optimization of Wire Harness Routing, Wire Count, Harness Length and Mass
- Allows for Increased Complexity to Accommodate Powertrain and Engine Management System Architecture Trends
- Reduced Form Factor and Weight Due to Optimized System Partitioning
- Potential Material Cost Savings Through Physical Integration (Elimination of Interconnect Layers and Enclosures)

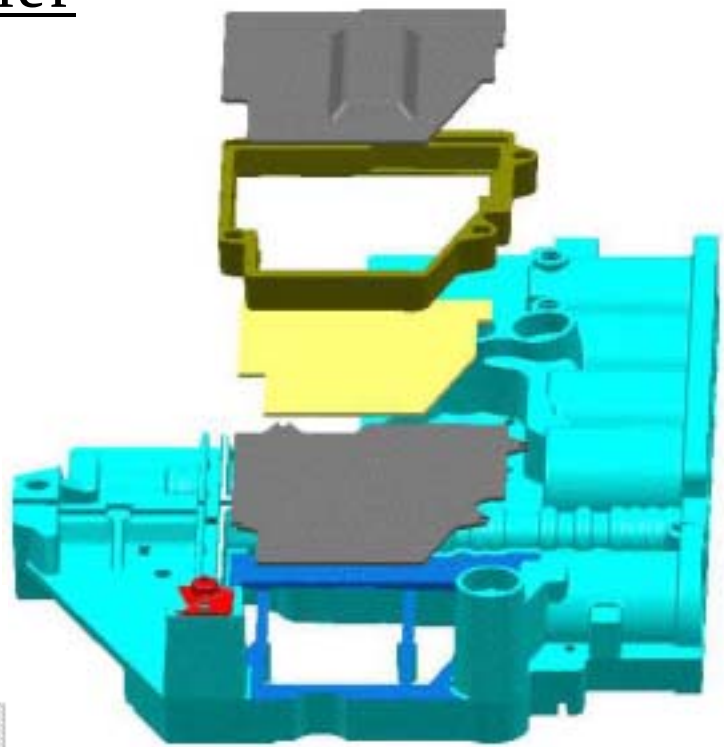
CONTROL MODULES

Example of Mechatronic Approach

Integrated Transmission Controller



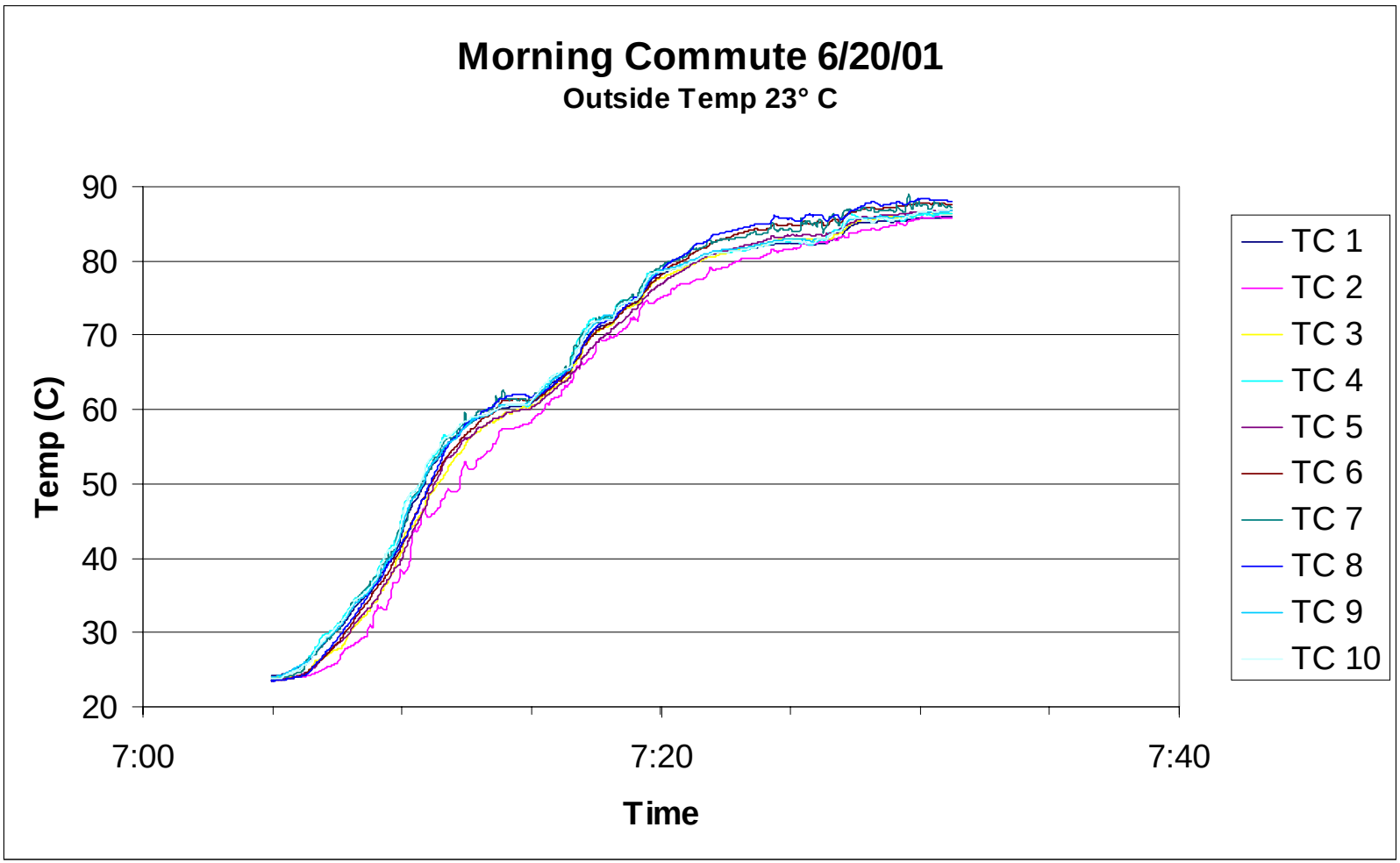




CONTROL MODULES

Measurement of Temperature Variations

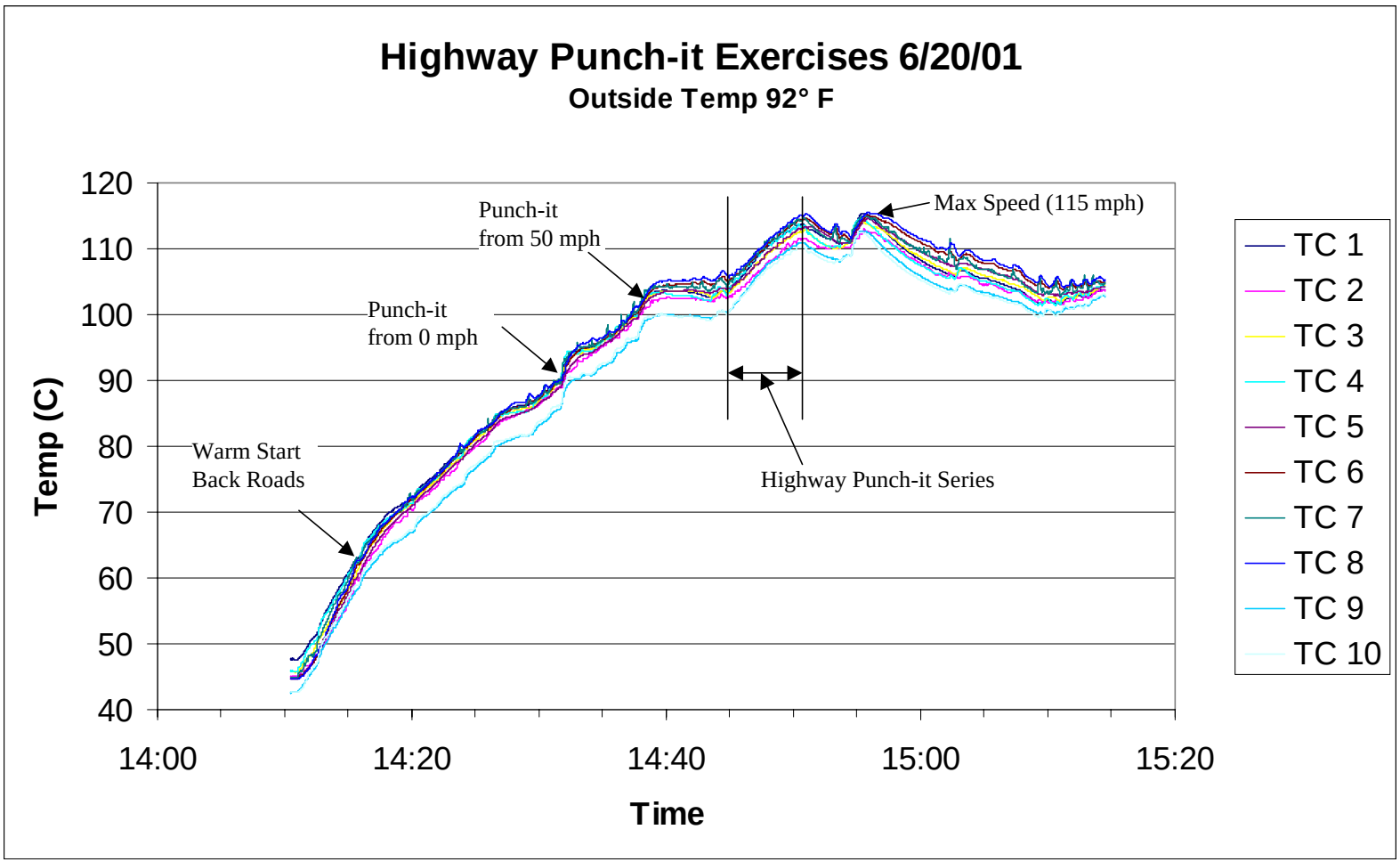
Integrated Transmission Controller



CONTROL MODULES

Measurement of Temperature Variations

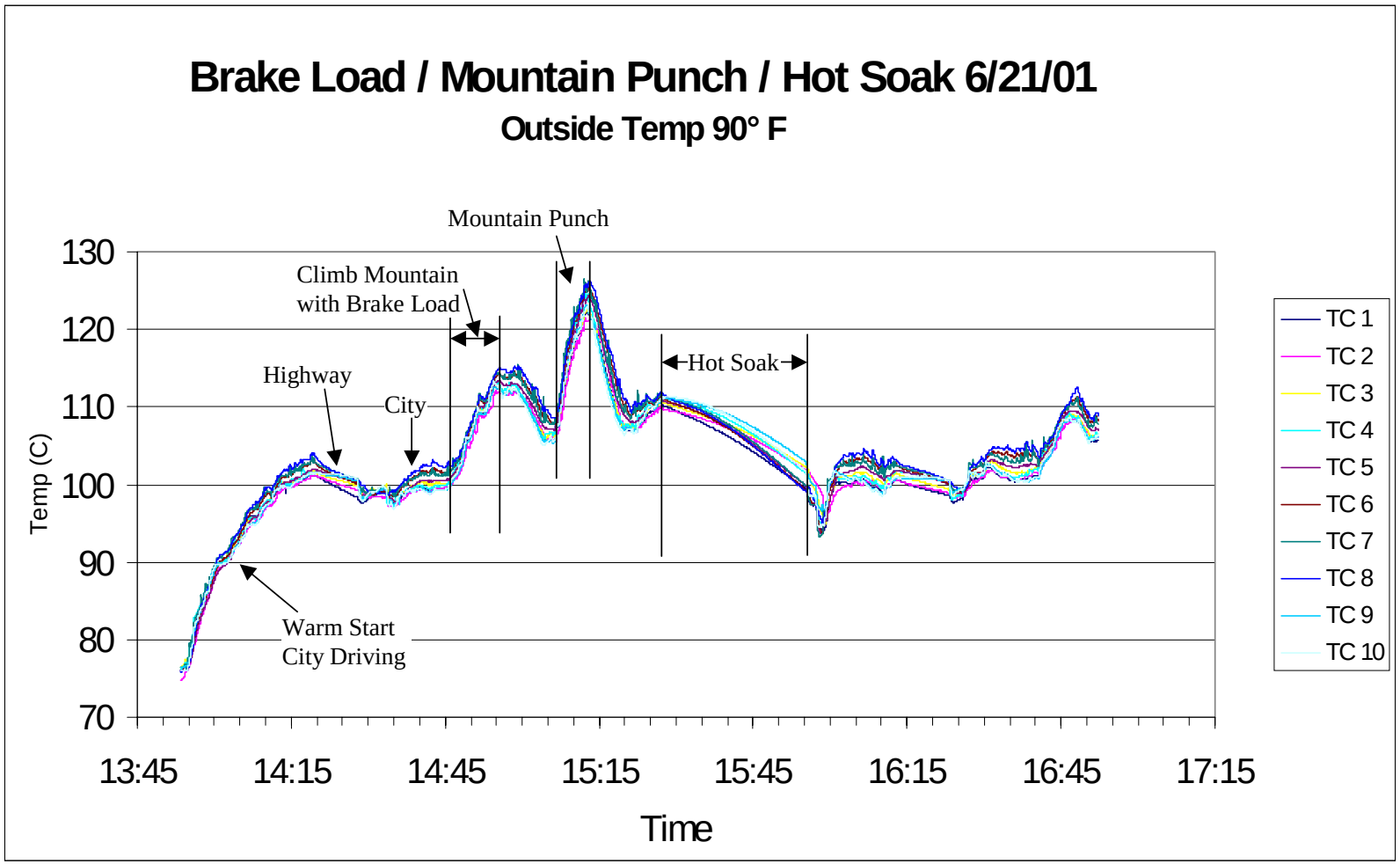
Integrated Transmission Controller



CONTROL MODULES

Measurement of Temperature Variations

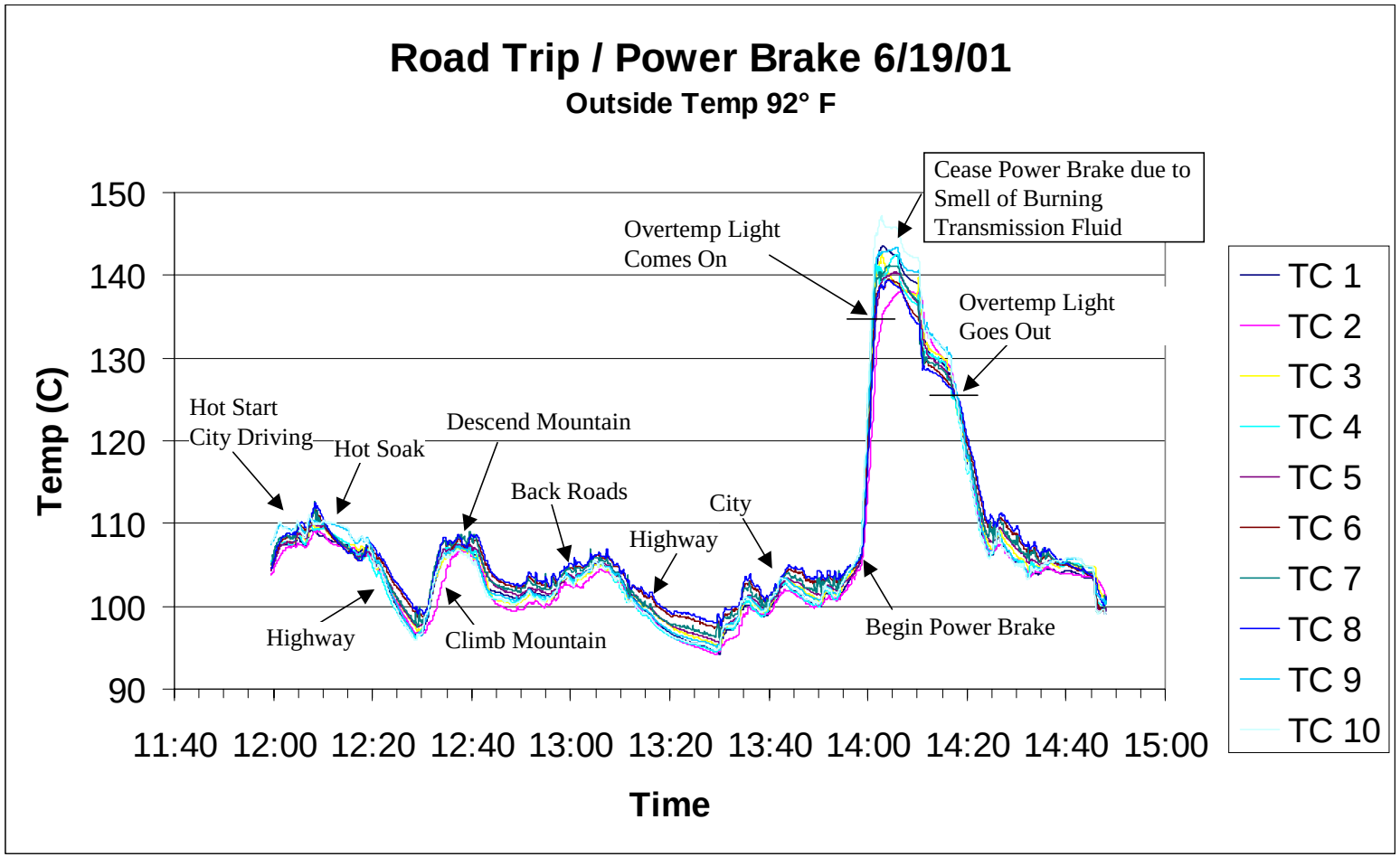
Integrated Transmission Controller



CONTROL MODULES

Measurement of Temperature Variations

Integrated Transmission Controller

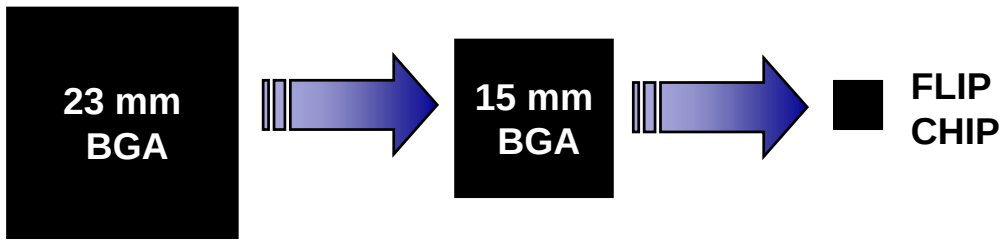


CONTROL MODULES

Enabling/Required Technologies

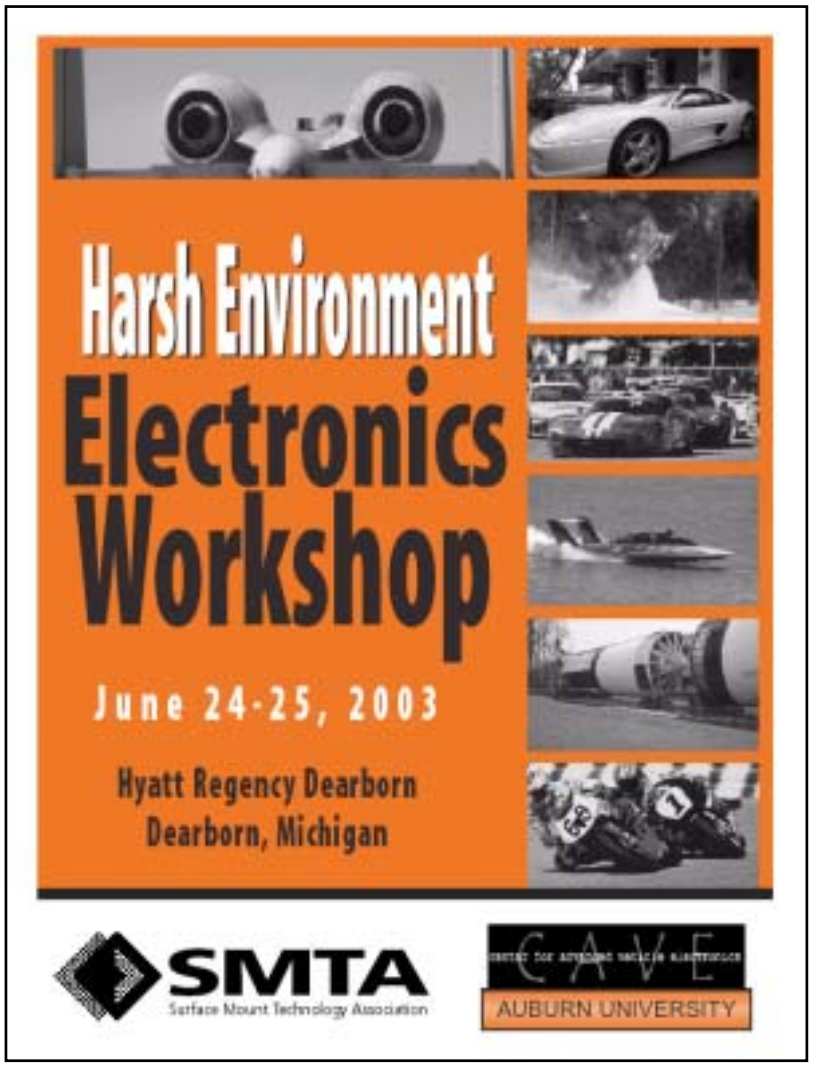
- Semiconductors
  - Silicon, SOI if Necessary
  - KGD for High Temperature
- High Temperature Substrates
  - Ceramics (LTCC, HTCC)
  - Laminate (NELCO, Polyimide, etc.)
- Components
  - BGA
  - CSP: Small BGAs
  - Flip Chip
- Passives
  - 0402 and 0201
  - Power/Current De-rating
- Solder
  - Transition to Lead Free

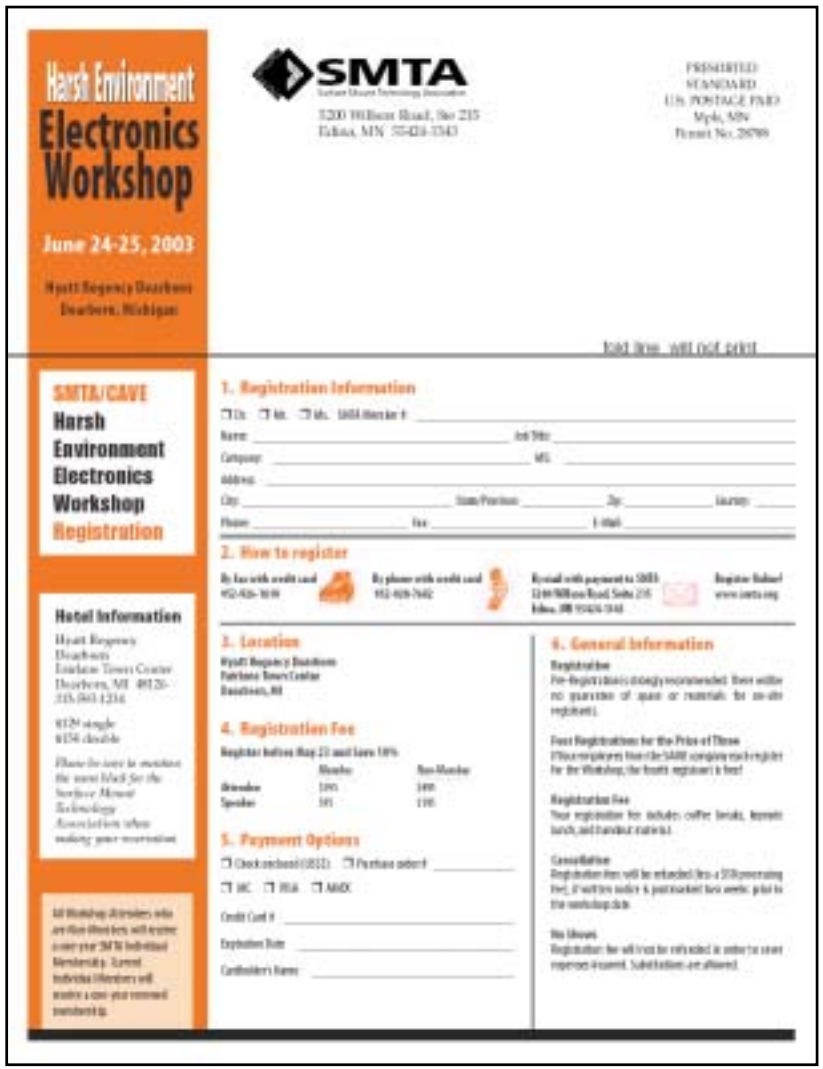
Cost Must be Low



RELATED WORKSHOP

Harsh Environment Vehicle Electronics



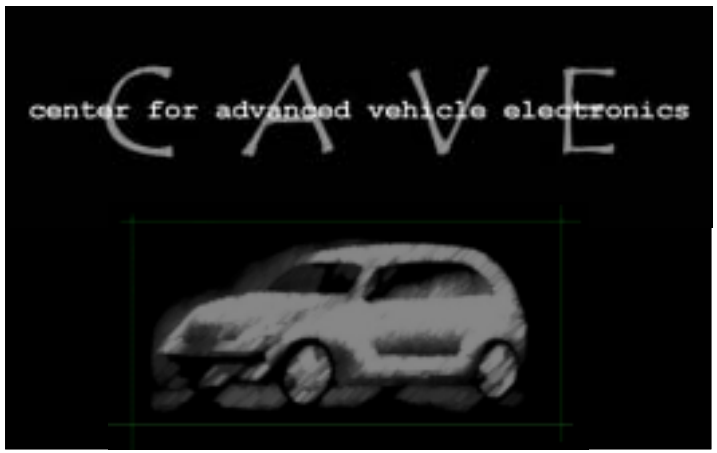


Center for Advanced Vehicle Electronics CAVE

CAVE

NSF Center for Advanced Vehicle Electronics

- A National Science Foundation Industry/University Cooperative Research Center (I/UCRC)
- Objective: Provide a Mechanism for Research and Development to Support Advanced Vehicle Electronics in Harsh Environments
- Demographics:
  - 12 Member Companies
  - 10 Faculty
  - 7 Staff
  - 36 Graduate Students
  - 7 Laboratories



MEMBERSHIP

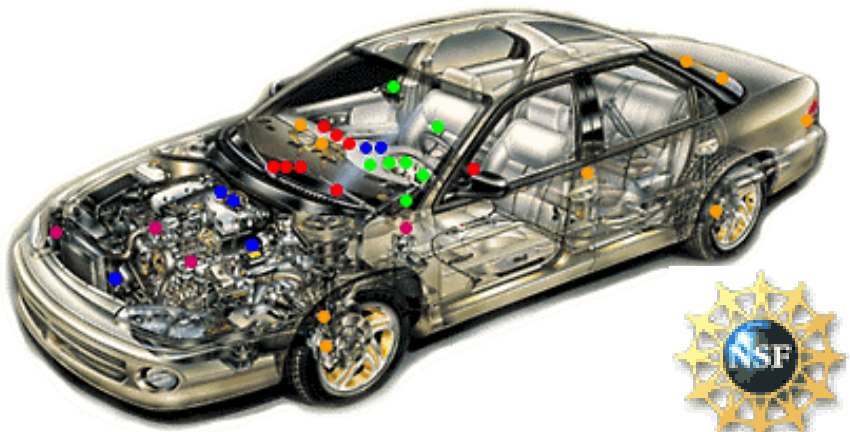
CAVE - Center for Advanced Vehicle Electronics

Cookson Electronics
A DIVISION OF COOKSON GROUP plc

CAVE
center for advanced vehicle electronics

Vehicle power and data solutions
YAZAKI
All Systems Go

DAIMLERCHRYSLER



NASA

molex

NSF

THERMOSET
Advanced Electronic Materials

LORD Chemical Products

LOCTITE

Photocircuits

MEMBERSHIP

CAVE - Center for Advanced Vehicle Electronics

Automotive – Aerospace & NASA - Military

CAVE: Center for Manufacturing and Reliability of Harsh Environment Vehicle Electronics

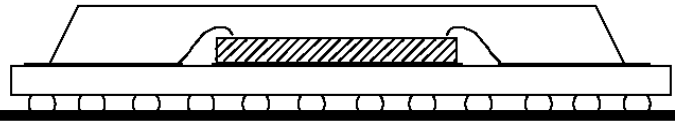
CURRENT PROJECTS

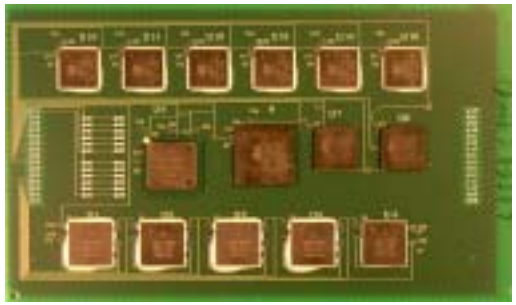
CAVE - Center for Advanced Vehicle Electronics

- BGA Reliability
- Flip Chip on Laminate
- Lead-Free Soldering
- High Temperature Electronics
- Connectors
- Correlation of Field Life with Accelerated Life Testing
- Modeling and Control of SMT Assembly Processes

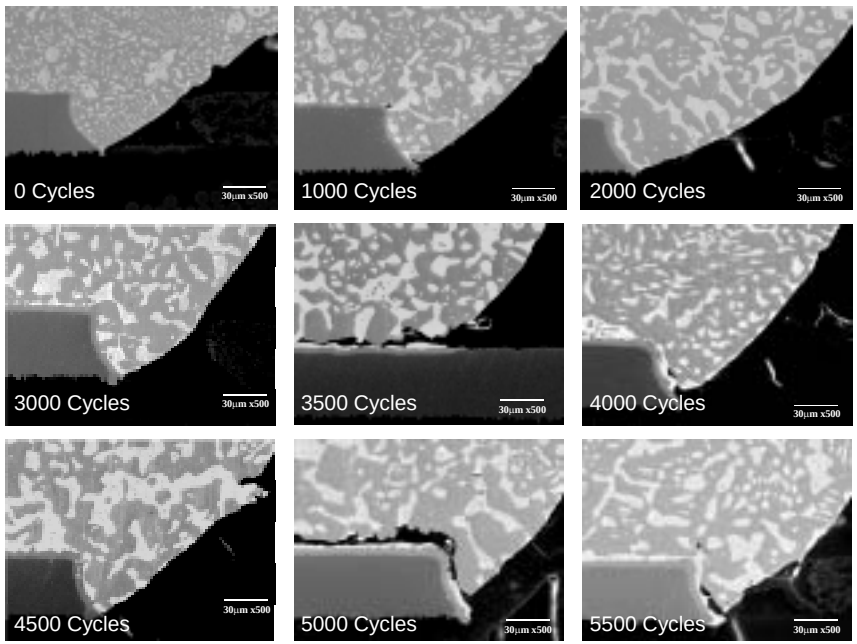
PROJECT

BGA Reliability

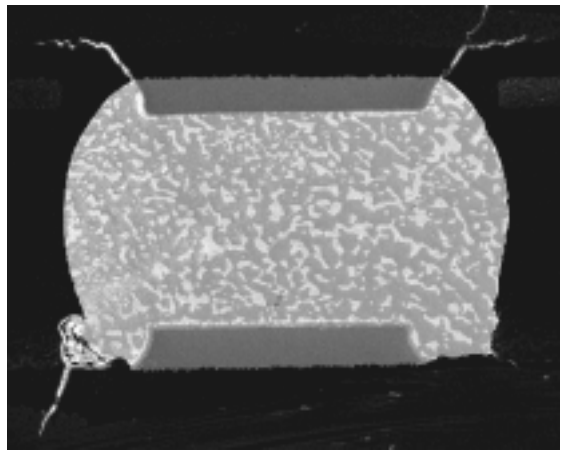


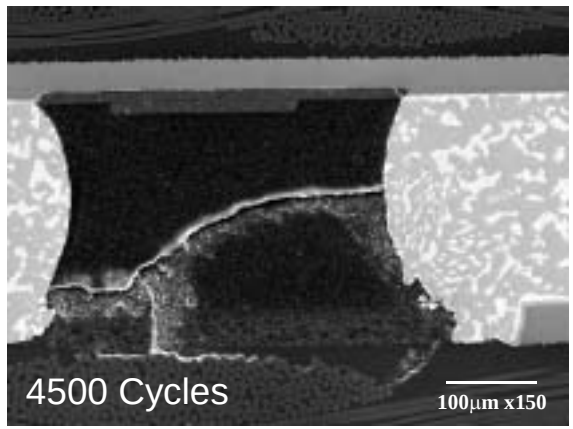


Solder Joint Damage and Crack Growth With Thermal Cycling and Aging



Failure Modes in Underfilled Components



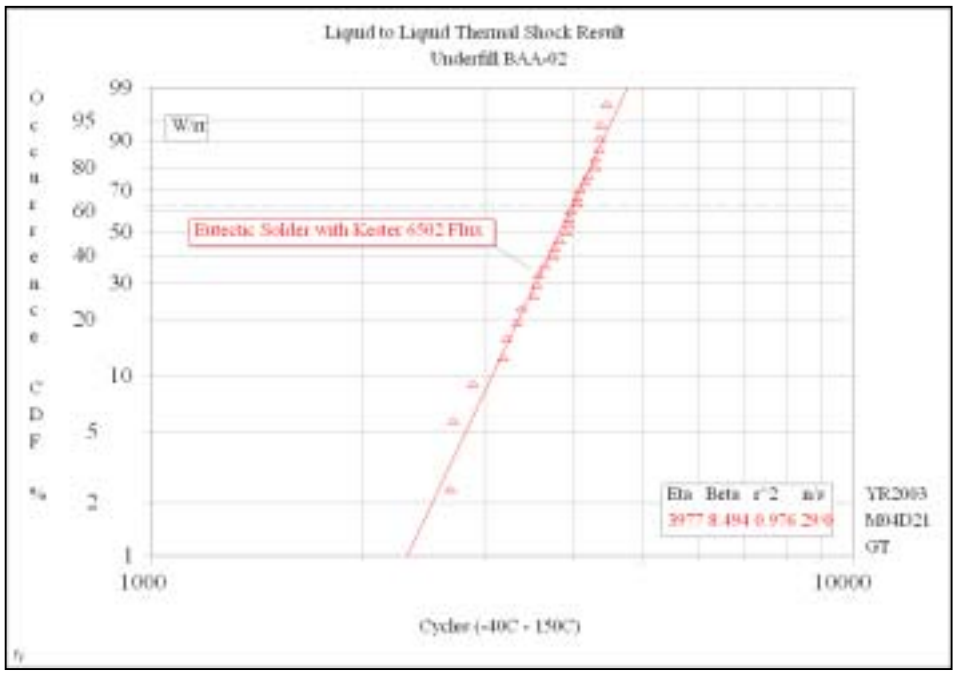


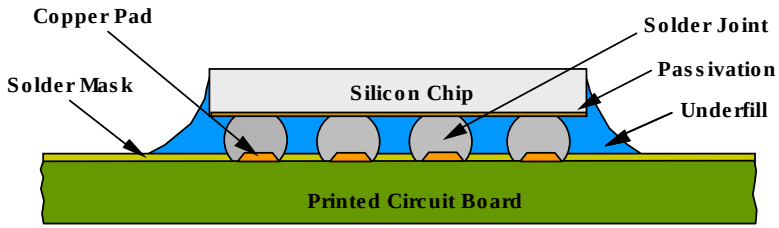
PROJECT

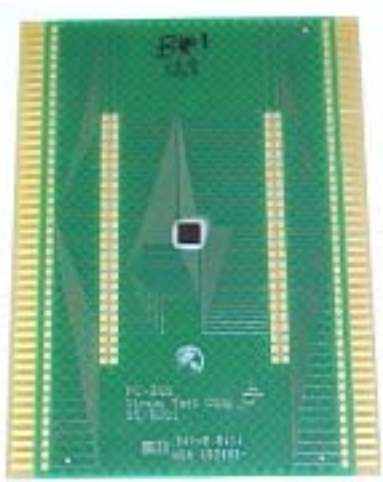
Flip Chip on Laminate

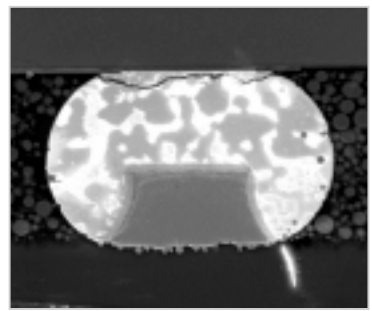
Reliability for Extreme Environments

-40 to 150 °C





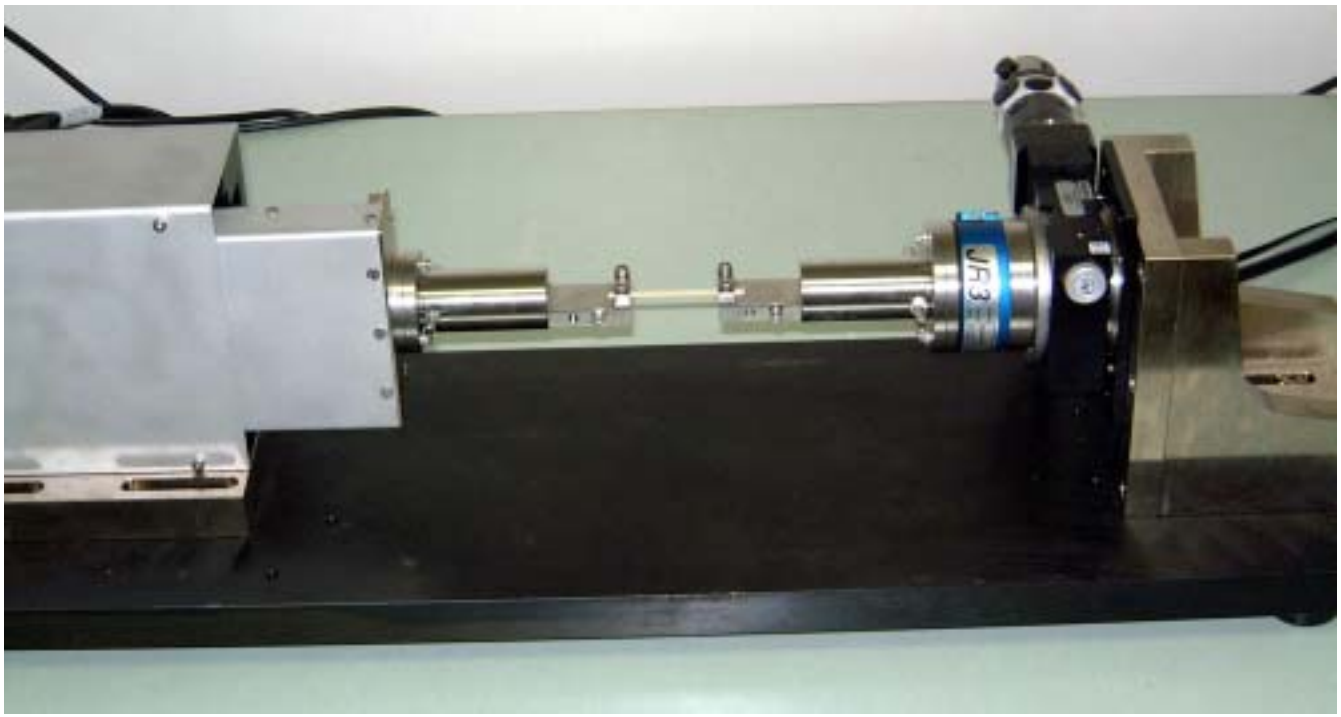




PROJECT

Flip Chip on Laminate

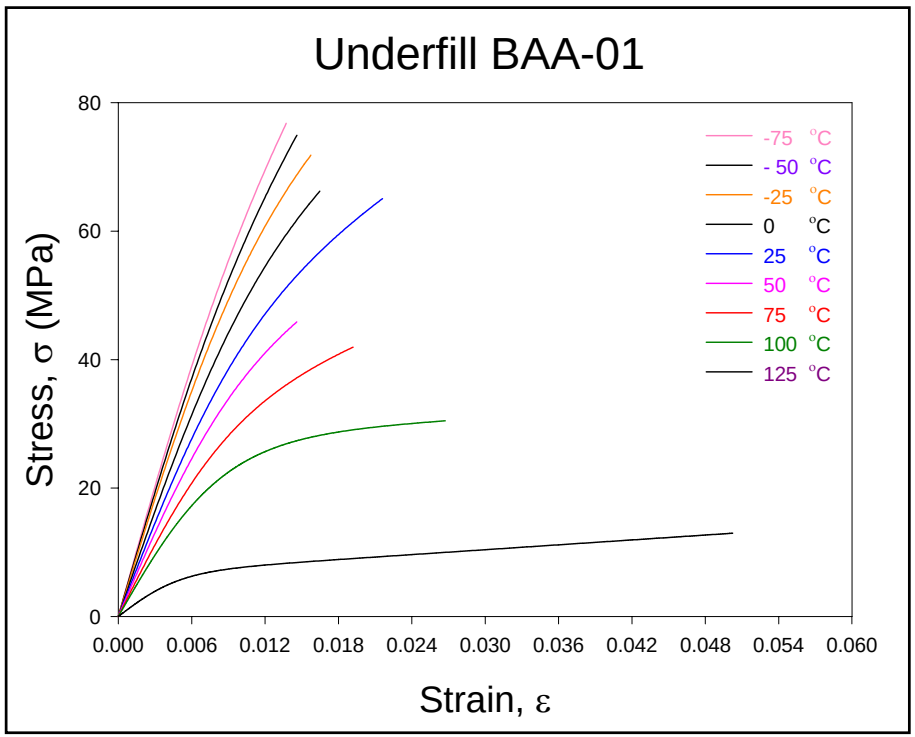
Microtester Characterization of Underfill Material Behavior



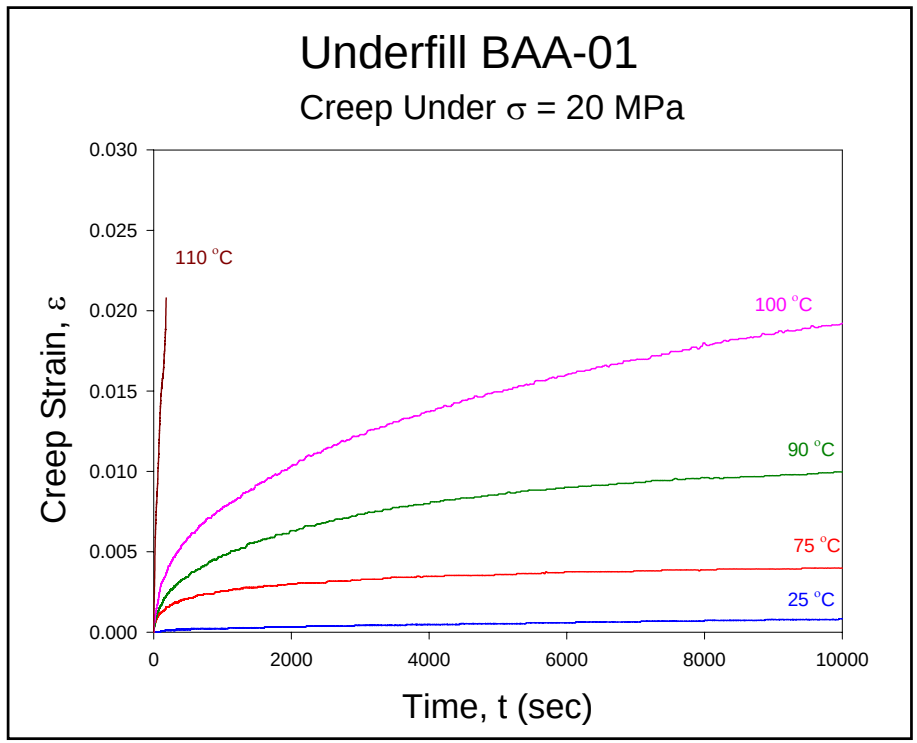
PROJECT

Flip Chip on Laminate

Underfill Stress-Strain Curves
-75 to 125 °C



Underfill Creep Curves
25 to 110 °C

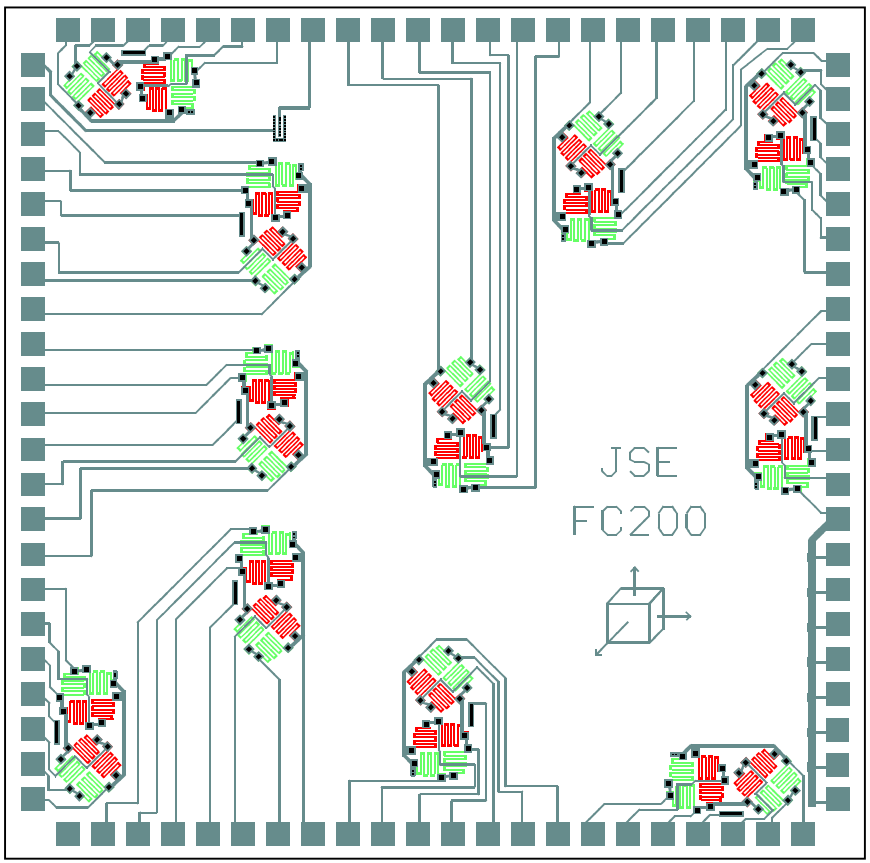


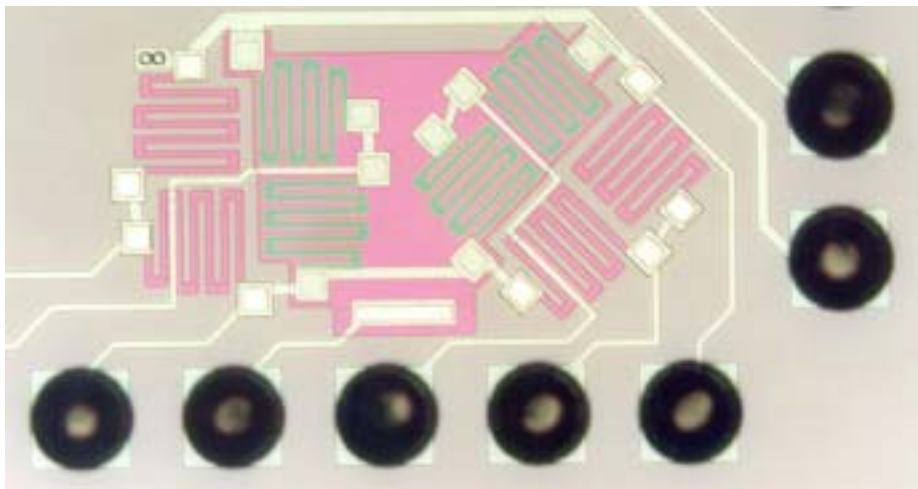
PROJECT

Flip Chip on Laminate

Test Chip Stress Measurements

(111) Silicon with Piezoresistive Sensor Rosettes



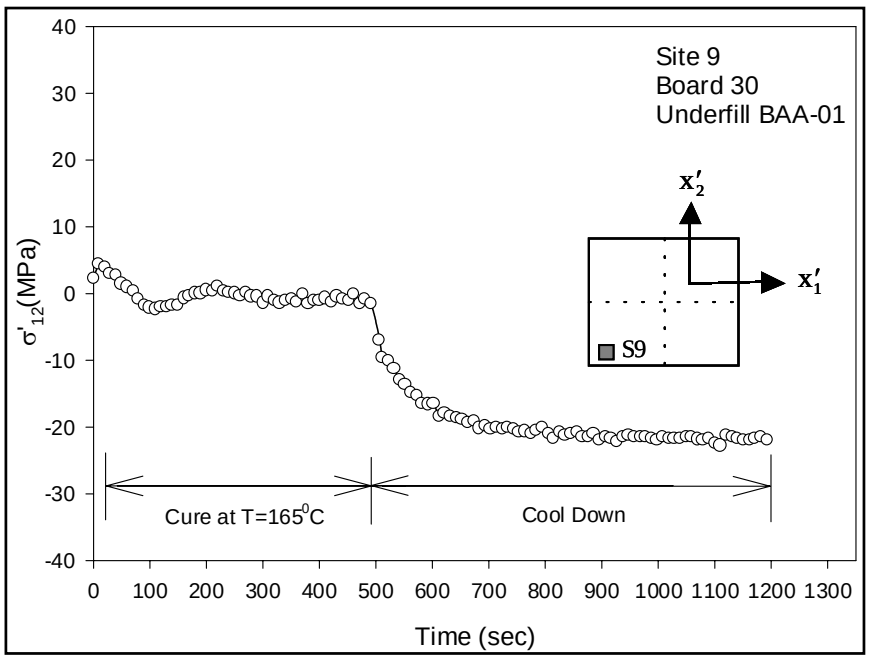


PROJECT

Flip Chip on Laminate

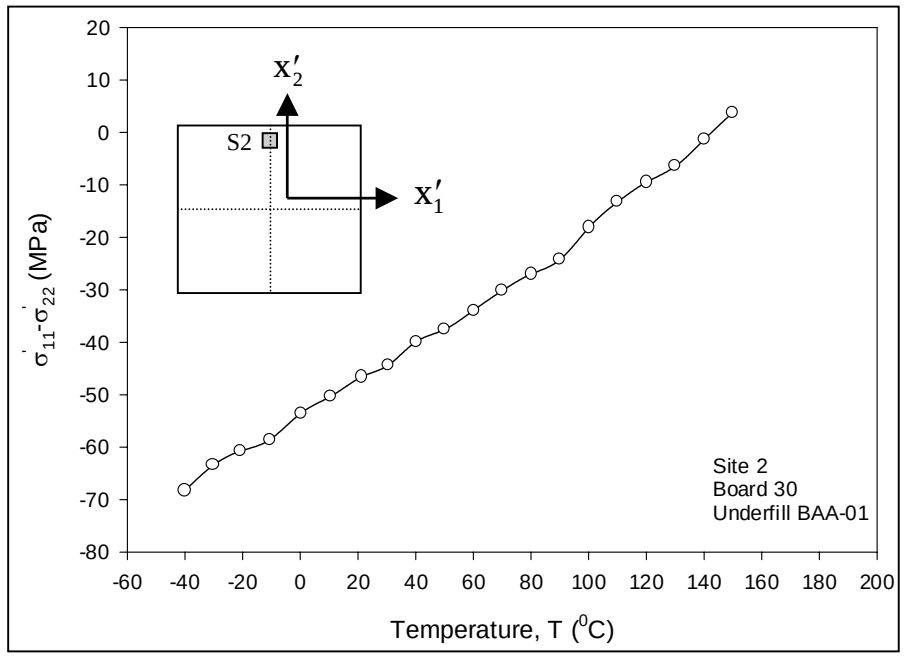
Curing Stress Measurements

+165 °C and Cooldown



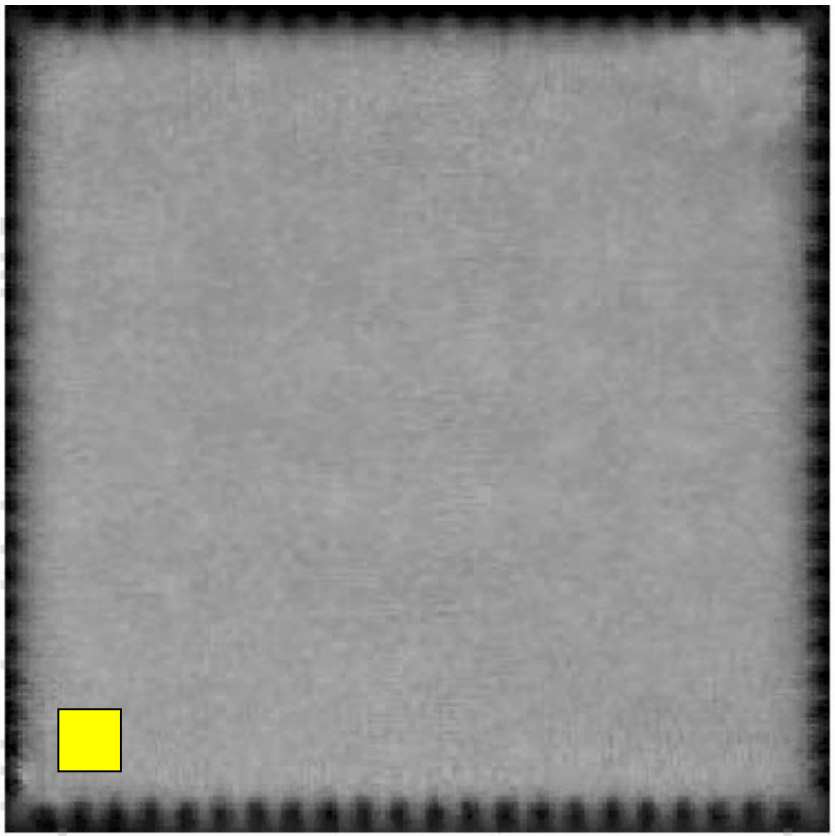
Assembly Stress Measurements

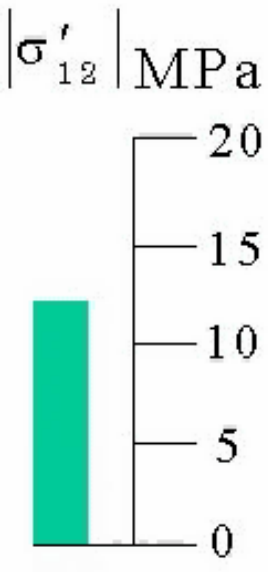
-40 to 150 °C

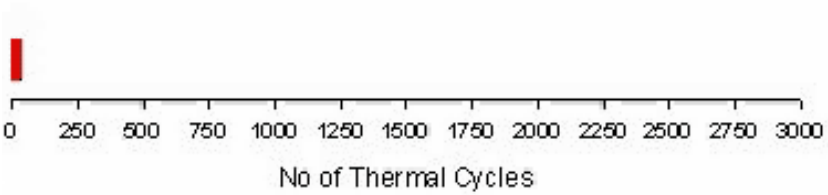


PROJECT

Flip Chip on Laminate



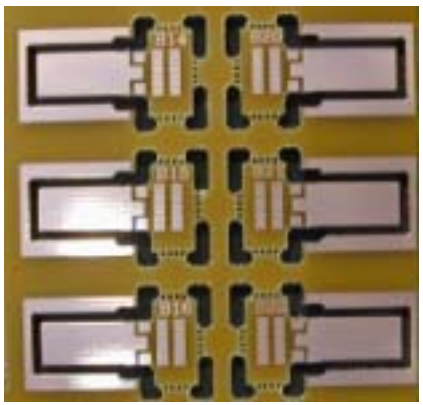


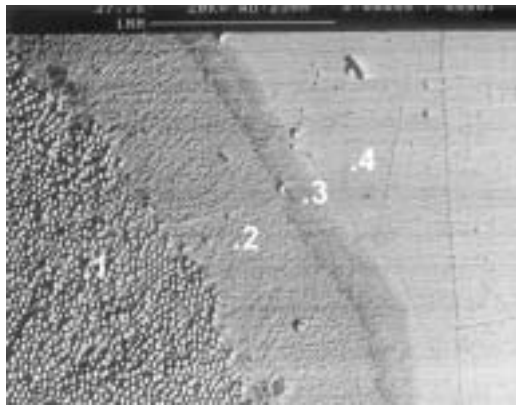


PROJECT

Lead Free Soldering / Connectors

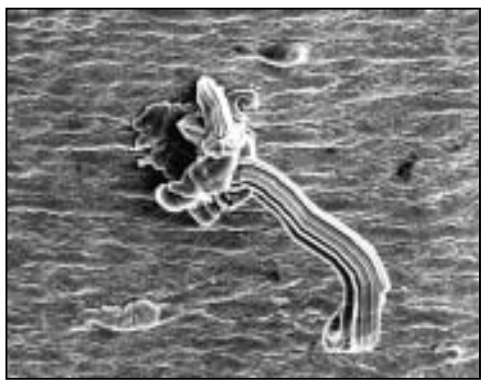
Wetting Studies

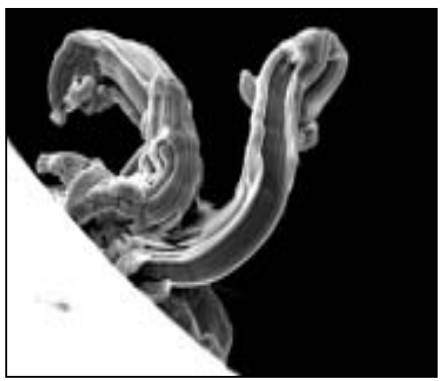


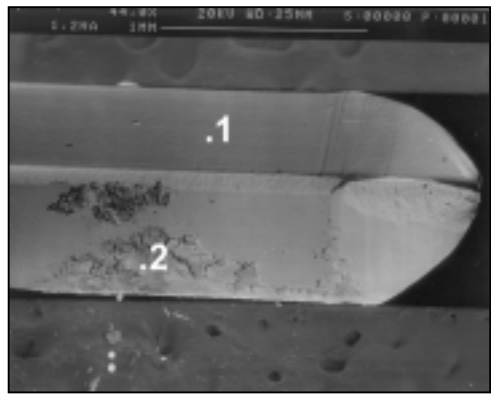


Vibration Induced Fretting Corrosion

Tin Whisker Growth with Extreme Environment Exposure Studies







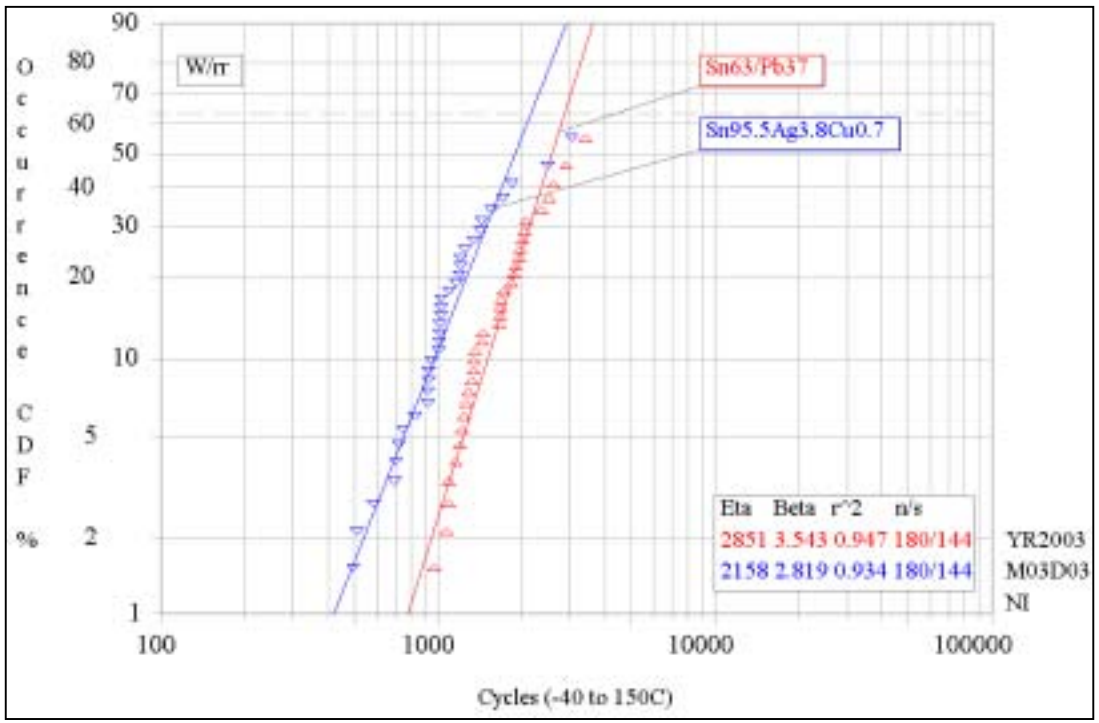
PROJECT

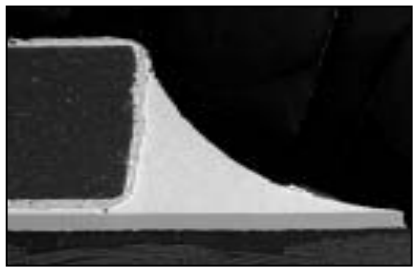
Lead Free Soldering

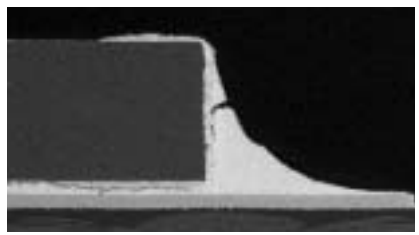
Center for Advanced Vehicle Electronics CAVE

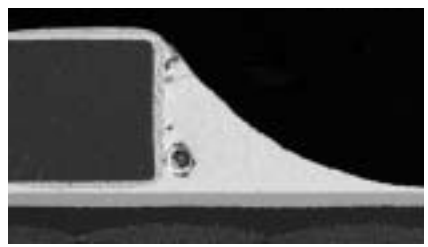
Solder Joint Reliability

-40 to 150 °C









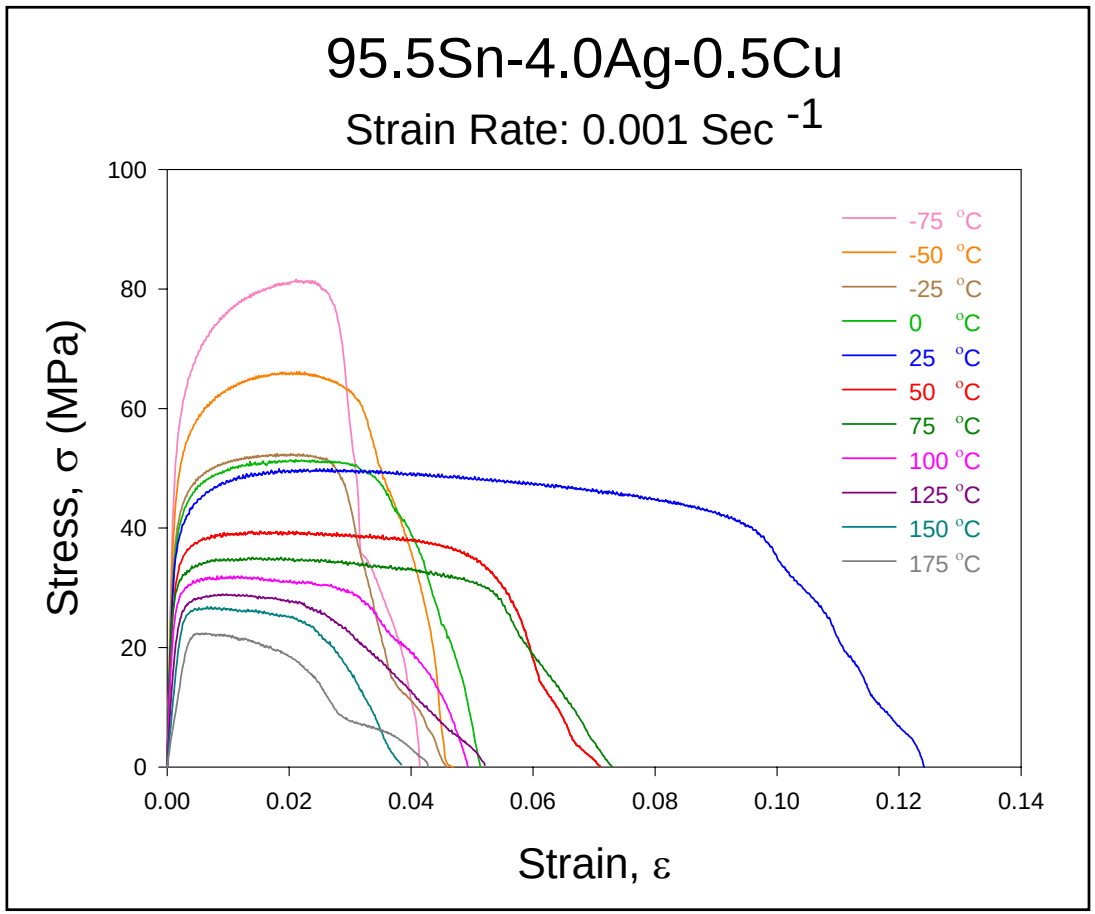
*Sn-Ag-Cu Worse Than 63Sn37Pb

PROJECT

Lead Free Soldering

Lead Free Solder Stress-Strain Curves

-75 to 175 °C

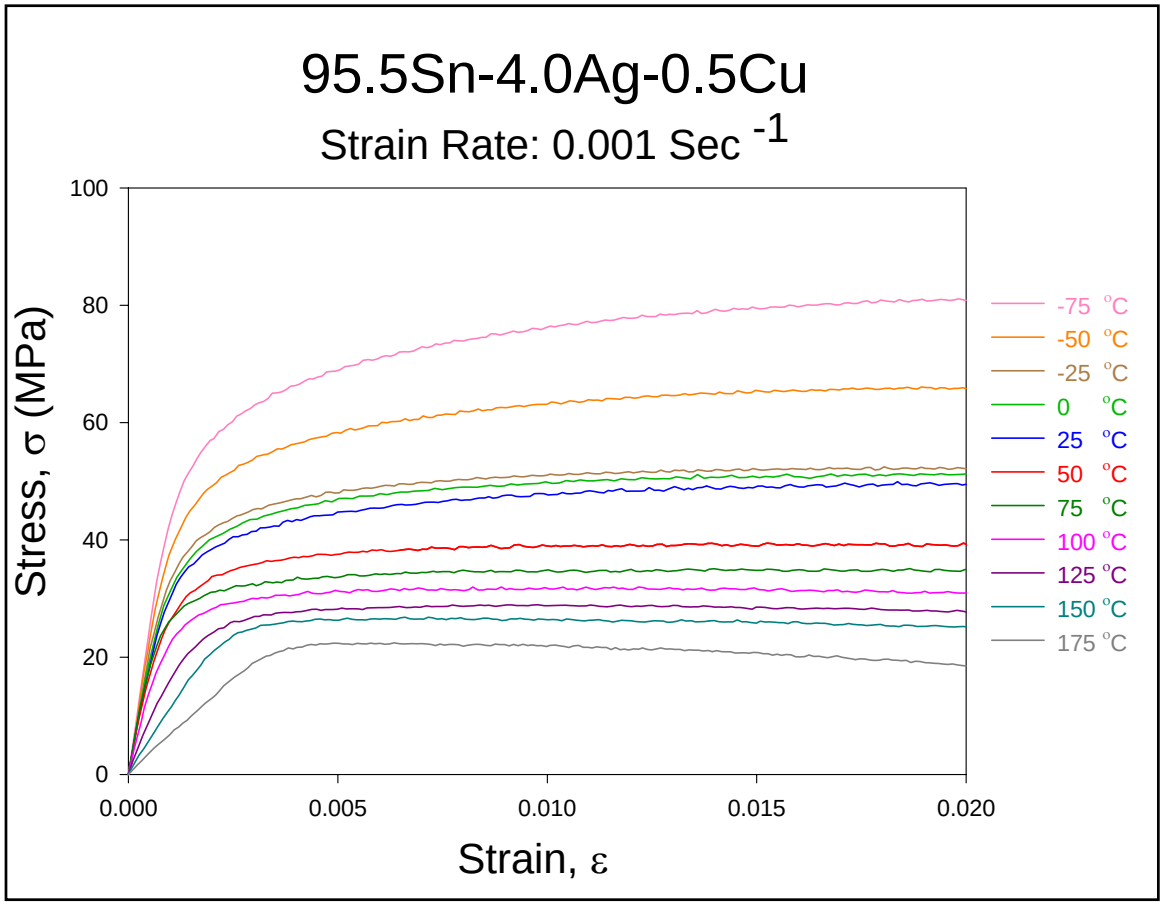


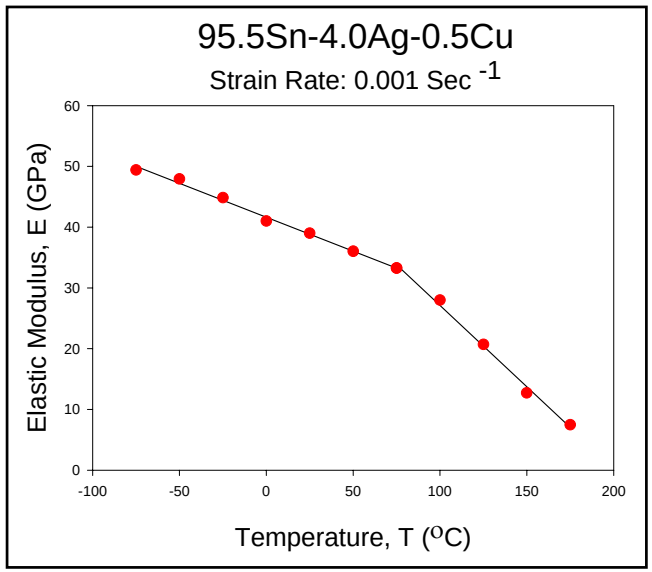
PROJECT

Lead Free Soldering

Lead Free Solder Stress-Strain Curves

-75 to 175 °C

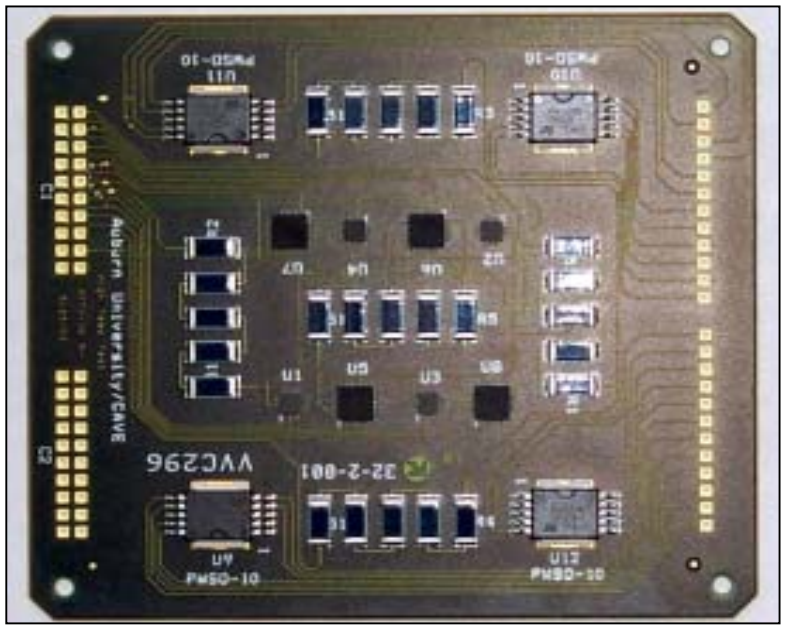




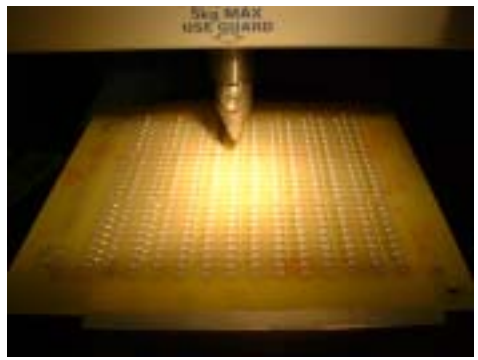
PROJECT

High Temperature Electronics

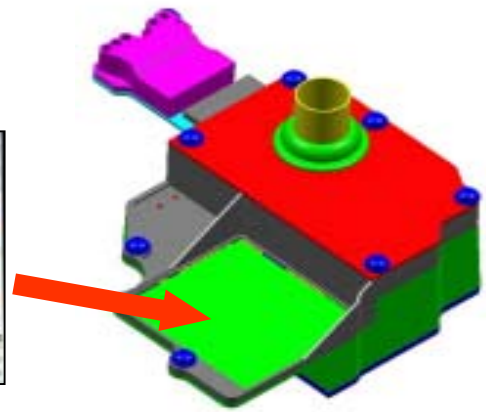
Metal-Backed Substrates



Wire Bond Strength Degradation

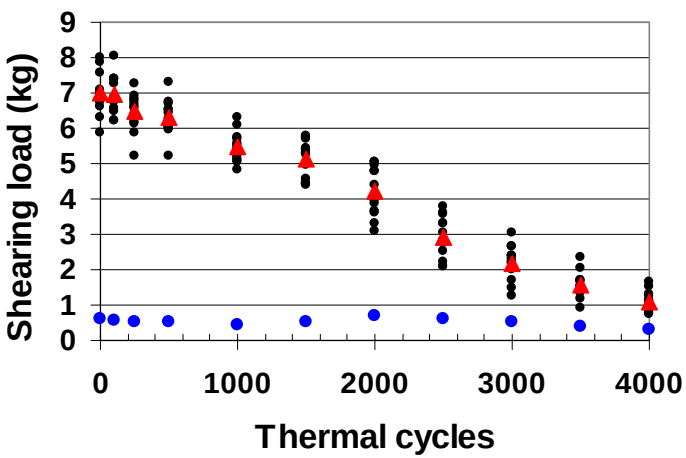


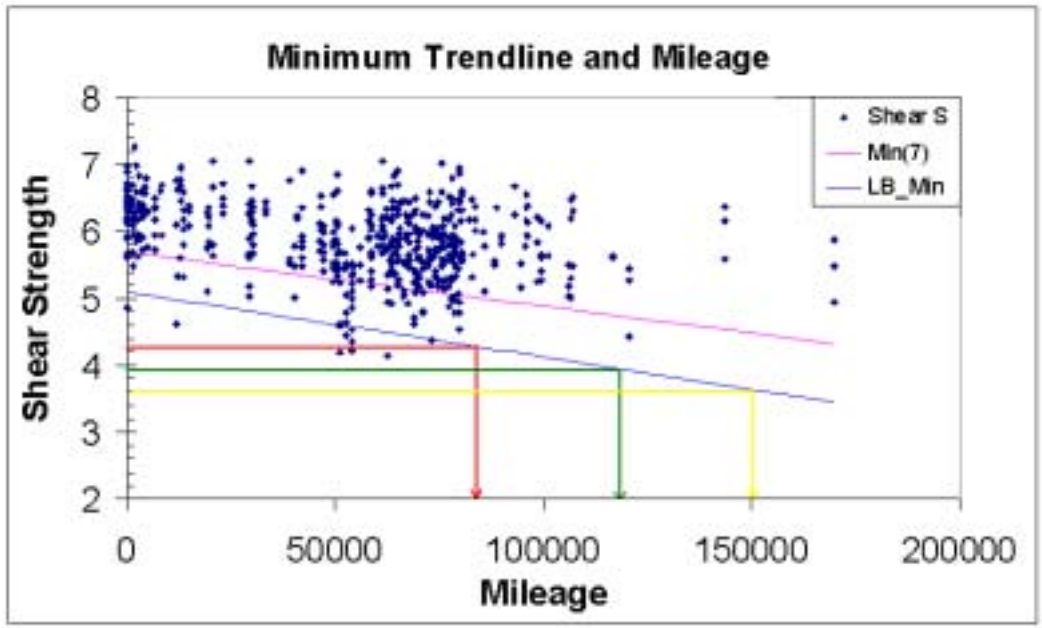
Mechatronic Applications



PROJECT

Correlation of Field Life with Accelerated Life Testing





SUMMARY

- Automotive Electronics are Increasing Greatly in Complexity Due to Legislative and Market Demands
- Trends for Underhood Controllers are Leading to a "Mechatronic" Approach, where the Electronics are Integrated into the Engine Block or Transmission Leading to a Design Temperature Range of –40 to 175 ^{o}C
- Automotive Underhood Control Modules Feature "*Mass Production Harsh Environment Consumer Electronics*"
- An Introduction to the NSF Center for Advanced Vehicle Electronics (CAVE) and Typical Center Research Projects was Given